# Software Supporting Cumulative Impact Analyses

## Prepared for

**The National Environmental Policy Act**
**Tools for Powerful Planning Using Cumulative Impact Analyses**

**Methodologies and Best Practices Workshop**

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# GOALS

- Explore a "language" and approach to cumulative impact analysis through systems modeling
- Review approaches categorized by level of detail
- Understand the breadth of resources

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# INTRODUCTION

The intended audience for this document is NEPA practitioners interested in understanding the use of software tools in the analysis of cumulative impacts. This audience has a full appreciation of NEPA from legal, policy, practical, social, and political standpoints. It is familiar with NEPA documents as comprehensive reports on the past and current state of the system within which an action is proposed. The audience understands NEPA documentation as analyses of direct and indirect consequences of proposed actions on system aspects such as the social, ecologic, hydrologic, and water/air quality.

This document attempts to provide a cursory introduction to software tools that are useful for analyzing cumulative impacts of proposed actions. Like the apparent endless nature of cumulative impact analyses, the wealth of tools useful to supporting such analyses is vast. This document begins to point us toward useful directions to begin exploring the possibilities.

The purpose of each of the chapters of this document is described here. We begin with a description of the challenge of cumulative impact assessment and then progress through techniques and approaches from least to most expensive in time and money.

A CUMULATIVE IMPACT APPROACH

The fundamental idea and challenge of cumulative impact analyses is presented graphically. The idea of understanding cause-effect chains that link proposed actions with impacts is followed by the idea of then developing cause-effect chains linking other activities to the most important of the identified impacts.

DECISION SUPPORT SOFTWARE

The purpose of NEPA is to inform a decision process. Therefore, efficient analyses must always keep in mind how developed information fits into that process. Ultimately, impacts (direct, indirect, and cumulative) must be evaluated with a common currency to allow for trade-off analyses. This chapter introduces simple decision support ideas and approaches that can be useful in focusing NEPA analyses.

SYSTEMS THINKING

Cumulative impact analyses require an expansion of the focus of an analysis to more aspects of the system. This chapter recognizes that systems thinking can occur at varying levels of details – from discussion among participants to thorough scientific analyses and application of powerful simulation models. The appropriate level is the least effective that will be acceptable to the analysis processes. The concept of feedback loops is also presented.

SYSTEMS MODELING WITH LISTS

A first step to formalizing our understandings of a system under consideration is to identify a proposed activity and simply list the direct impacts of that activity. A list of direct impacts associated with each of these can be developed, and so on. The importance of limiting items in the list to only direct impacts is stressed.

SYSTEM MODELING WITH GRAPHICS

Following on the previous chapter, systems thinking with simple graphics on paper is presented. This approach is easily accessible to all participants – allowing a capturing of listed cause-effect chains in a readily understandable graphical format – without mathematically formalizing the relationships.

SYSTEMS MODELING WITH A SPREADSHEET

Once lists of direct impacts are developed, it is possible to begin pulling all of those lists together into a whole. One way that is accessible to many is through spreadsheets (e.g. Microsoft's Excel).

Spreadsheets offer the opportunity to capture strengths of impacts using numbers and begin to provide some analysis opportunities.

TIME AND SPACE

Cause-effect chains captured thusfar in the above chapters can treat the system as a homogeneous whole. Recognizing that different aspects of the system occupy different times and space of the system can be very useful in uncoupling presumed cause-effect links.

GIS – Geographic Information Systems

Although GIS is a familiar technology, few understand the wide variety of available analyses. This chapter provides a quick overview of GIS capabilities.

SYSTEM SIMULATION MODELING

Formally capturing the cause-effect relationships and the knowledge of the system state (as captured in GIS) into software allows the development of models – abstractions of the reality – that can simulate salient aspects of the system under study. This chapter introduces basic system simulation modeling ideas, techniques, types, and approaches.

DETAILED DISCIPLINE SPECIFIC SIM MODELING

The vast majority of simulation models applicable to NEPA analyses are discipline specific. An introduction to models in hydrology, ecology, and forestry is provided.

INTERDISCIPLINARY SYSTEM SIMULATION MODELING

Cumulative impact analyses require the development of an understanding of the landscape system as a whole and can make the application of detailed discipline specific models inadequate. Cause-effect chains crossing traditional academic boundaries can require difficult inter-model connections.

SIMULATION MODEL DEVELOPMENT ENVIRONMENTS

Although discipline-centric models are often powerful and accurate, their typical black-box nature and the inherent difficulties connecting models from different disciplines encourages many to build their own models to meet their specific needs. Instead of starting with simulation models, analysts can choose to begin with open-ended simulation model development environments.

SIMULATION MODEL DEVELOPMENT STEPS

Each system for which a NEPA document is developed is understood by the professionals involved in the process. The most useful models are those that capture these understandings and reflect back the implications of those understandings. This chapter discusses generic approaches to the necessary steps required for turning understandings of the system into a locally specific model.

A NEPA WORKBENCH

This chapter briefly introduces ideas of a general-purpose set of tools that anyone developing NEPA documentation may use for a rapid initial assessment of the most important issues.

Appendix A: DEM Fun

GIS is generally viewed as a map storage and display system, but the analysis options are substantial. A demonstration of the breadth of analysis possibilities is represented in this series of maps – all generated from a digital elevation model (DEM).

Appendix B: Five Approaches to Modeling

This appendix describes common sense models, rule-of-thumb models, expert models, scientific models, and multi-disciplinary management models.

Appendix C: Modeling Wisdom
A one-page cheat sheet of modeling wisdom, rules, and use guidelines.

Appendix D: Internet Web Sites To Support Source Water
Over 200 Web sites associated with water systems management, data, models, and organizations.

# A CUMULATIVE IMPACT APPROACH

### *What is the challenge?*

NEPA requires that direct and indirect impacts of proposed projects be evaluated with respect to environmental, ecological, natural resources, and social aspects (Figure 1).

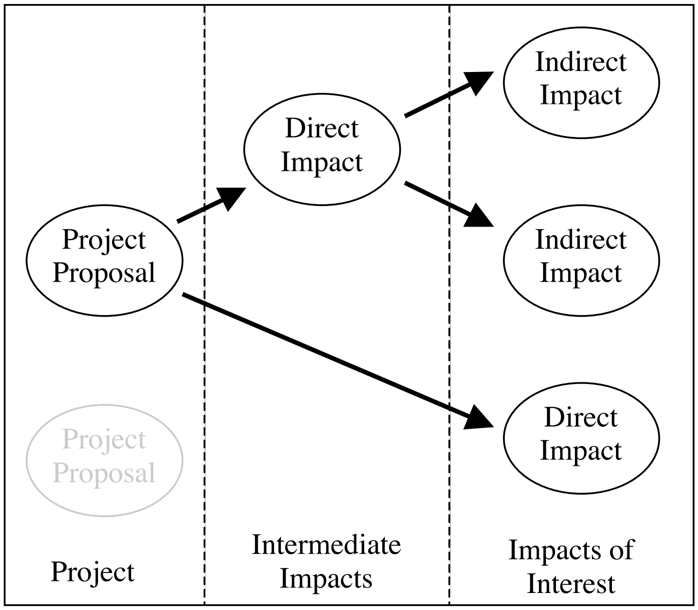



**Figure 1: Direct and Indirect Impacts**

NEPA also requires that cumulative impact analyses be conducted to understand the impacts in the context of other activities that have similar impacts (Figure 2). A cumulative impact analysis must therefore look at the entire system over the timeframe of the study with respect to the impacts of interest associated with the proposed project.

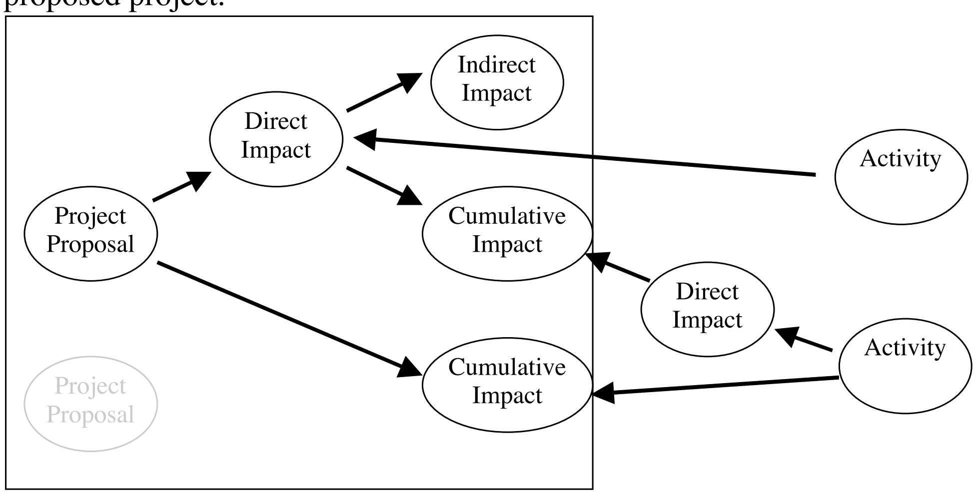



**Figure 2: Cumulative Impacts**

**The problem is that a NEPA cumulative impact analysis appears to overwhelm the NEPA analysis resources – requiring far more time, money and patience than is available.**

### *Approaching NEPA Cumulative Impact Analyses*

1. Scope
    a. Identify direct and indirect impacts-of-concern of proposed projects
        i. Identify need for a project
        ii. Identify project proposals
        iii. Develop conceptual cause-effect relationships connecting project proposals to impacts-of-concern
        iv. List impacts-of-concern
    b. Identify current and future activities that may affect the same impacts-of-concern
        i. For each impact-of-concern, develop conceptual cause-effect relationships connecting activities to them
        ii. Identify other activities-of-concern
2. Study
    a. Analyze the likely future impact of other activities-of-concern on the impacts-of-concern
    b. Analyze the impact of each proposed project on the impacts-of-concern
3. Report
    a. The likely future of the system without any project
    b. The likely future of the system with each proposed project

The flow chart in Figure 3 grossly captures steps that can be used to complete an environmental impact analysis. We, of course, start with a need for a project and identify alternatives to meet that need. Each alternative is evaluated with respect to the direct and indirect impacts. Each important impact is then identified with cause-effect chains linking it to other aspects of the local system. These are then assembled for analyses. System analyses (covered later) are then applied, starting with the least expensive approach and moving to more expensive approaches if necessary and affordable.

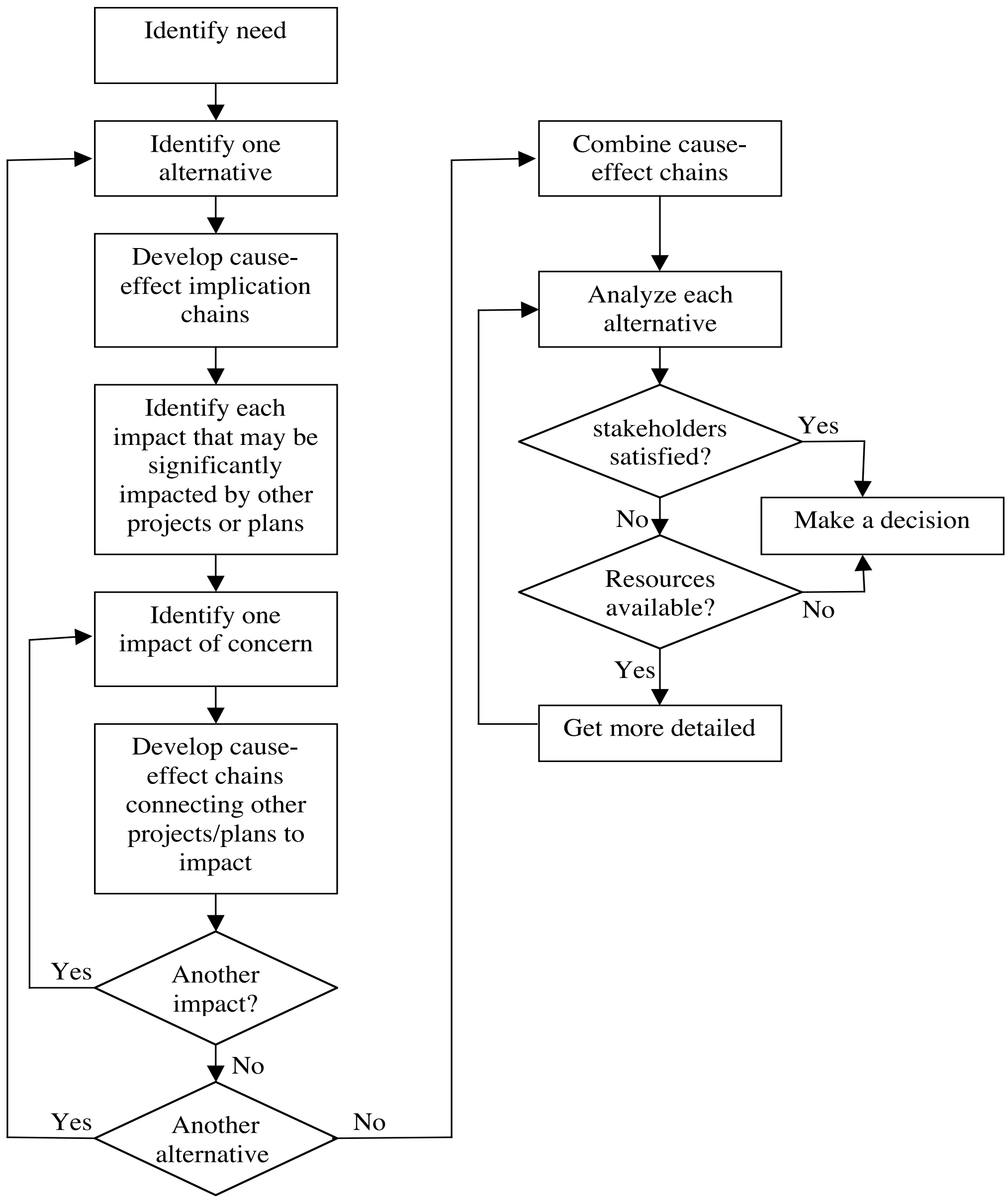



**Figure 3: A Cumulative Impact Analysis Approach**

## *Techniques Involved*

- Decision support software
  Software that helps individuals and groups understand and used their preference trade-offs
- Systems thinking
  Cognitive approaches to identifying, understanding and using cause-effect relationships
- Systems modeling
  with paper, spreadsheets, graphics, and software
- GIS

## *Cautions*

- The process is human – human preferences, human opinions, human laws and regulations, human limitations.
- Complex and complicated systems are involved.
- We each see only part of the system (elephant).
- Scientists “on tap”, not “on top”

- Scientists are often stakeholders, not sources of unemotional wisdom
- There is only so much time and only so much money
- There is never enough time or money to do it right, but there is always time and money to do it over.
- The greater the stakeholder interest and less the scientific uncertainty, the less science is used to make a decision (Figure 4)

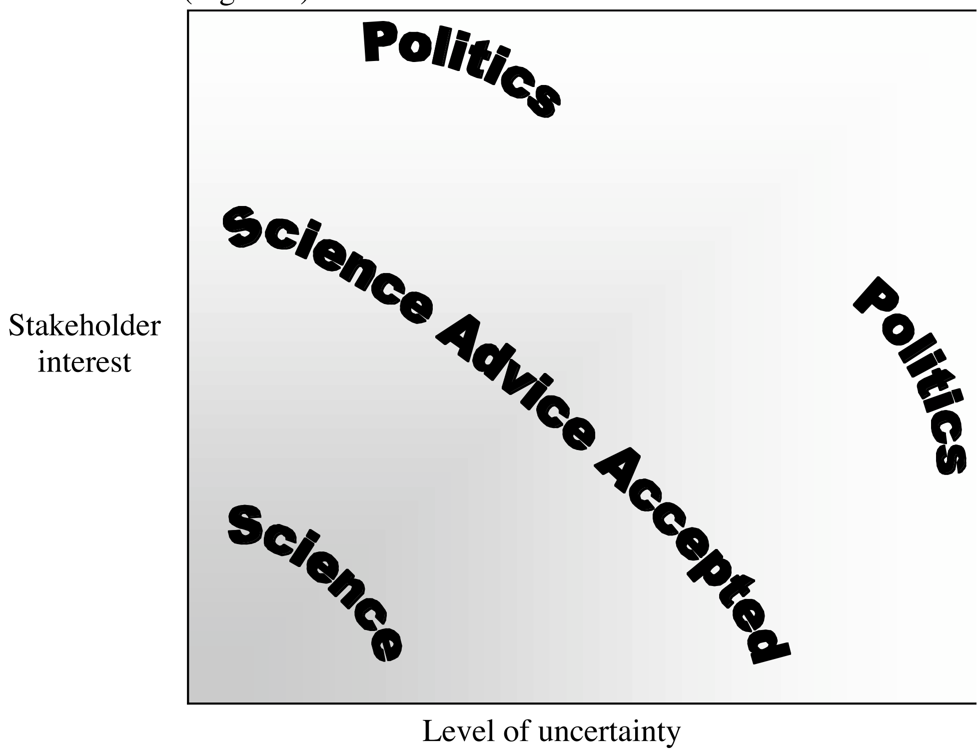



**Figure 4: Process must match scientific uncertainty and stakeholder interest**

### *Feedback Loops*

Human beings are relatively good at understanding system consequences with straightforward cause-effect relationships, such as the system in Figure 5.

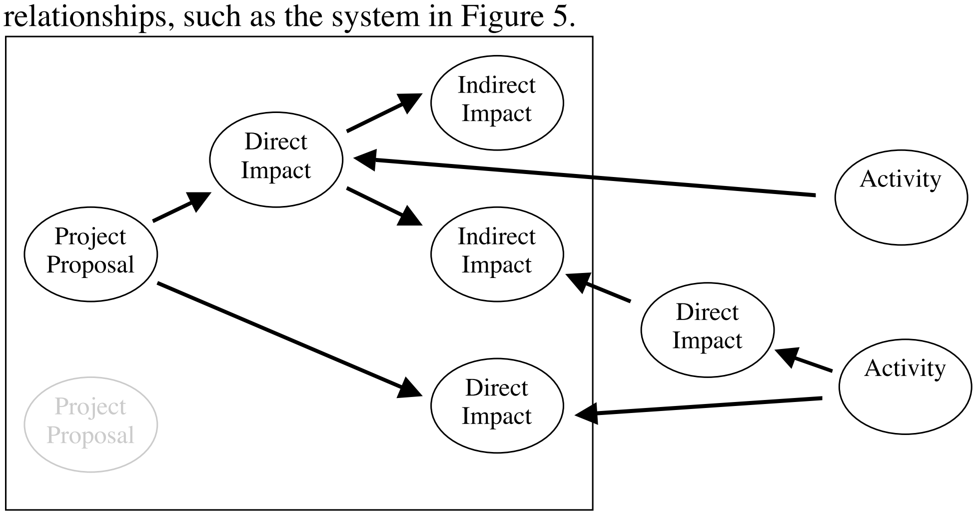



**Figure 5: System Without Feedback Loops**

Even a single feedback loop inserts a level of complexity that we cannot easily understand in a system (Figure 6). These systems are often inadequately analyzed with available single-discipline simulation models.

Important feedback loops make cumulative impact analysis particularly difficult and expensive.

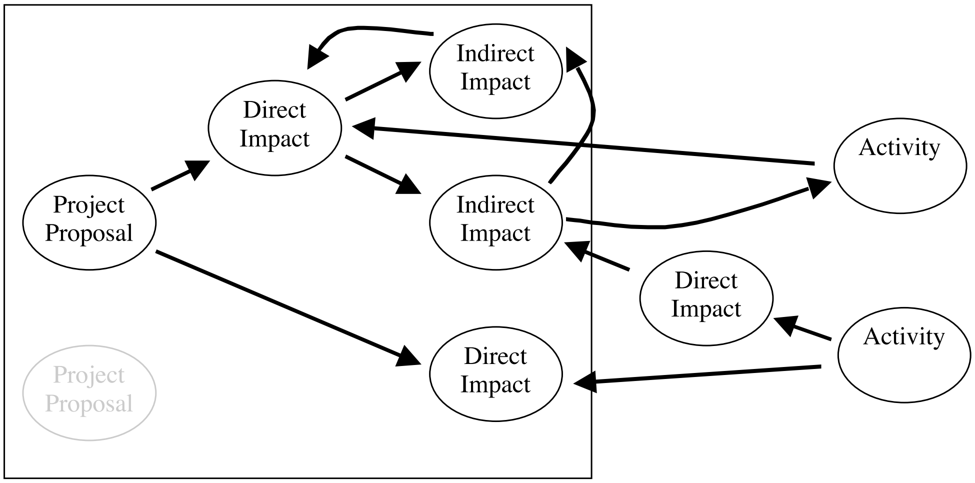



**Figure 6: System With Feedback Loops**

### *Exercise*

- Pick a proposed project (real or imaginary) that needs a NEPA analysis.
- Identify direct social, ecological, environmental, hydrologic, and other impacts.
- Identify indirect impacts.
- Which direct and indirect impacts are impacts-of-concern?
- Identify other activities that directly impact these.
- Identify activities that direct these activities, and so on.
- Connect all impacts with arrows. Use arrow width to indicate relative strength of cause-effect relationships.
- Identify the other activities that are of greatest importance on the future of the impacts-of-concern.

# DECISION SUPPORT SOFTWARE

### *Fighting words*

I hate it
I love it
Over my dead body
It's the worst thing that could happen
It'll dramatically improve the economy
We need this project
We can't afford the project

### *Possible Decision*

Sometimes, only unanimous decisions are made

- We agree that we want everything
- We agree to study the problem more

Consequences

- Non-optimal decisions
- Volunteers burn-out. Then start with new volunteers
- Stalemate
- No progress

The way out: compromise, trade-offs

### *Start quantifying the statements*

Rate your feeling on a scale of 0 (absolutely not) and 10 (absolutely yes)
Benefits: improves communication

### *Multi-Criteria Decision Making*

<u>Simple Weighted Averages</u>

Benefits: Conceptually easy, paper and pencil, good to get collective decisions, easy spreadsheet
Costs: Deceptively complicated

**Approach**

1. Identify competing project proposals
2. Identify impacts of importance
3. Identify relative importance of each impact
4. Identify impact (scale of 1-10) of each proposal on each imp0act
5. Multiply importance values times impact values and sum
6. Rank-order alternatives.

**Example**

| | Recreation | Housing | Attractiveness | Tax base | Jobs | Agriculture | Habitat | Water Quality | Air Quality | Water | Electric | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Importance-> | 10 | 10 | 5 | 18 | 10 | 5 | 9 | 3 | 10 | 10 | 10 | 100 |
| Proposal | | | | | | | | | | | | |
| proposal 1 | 3 | 4 | 2 | 5 | 3 | -3 | -10 | -5 | -8 | 3 | 2 | 50 |
| proposal 2 | 10 | 6 | 2 | 5 | 5 | -4 | -6 | -2 | -1 | 4 | 7 | 330 |
| proposal 3 | 5 | 4 | 1 | 10 | 10 | -5 | -2 | -2 | -1 | 3 | 4 | 386 |
| proposal 4 | 8 | 6 | 5 | 5 | 5 | -4 | -8 | -3 | -6 | 1 | 4 | 194 |

**Figure 7: Simple Decision Matrix**

**Where do the impacts come from?**

- Local stakeholder concerns

**Where do the proposals come from?**

- Local stakeholder suggestions
- Scientists/advisors

**Where do the impact-values (values in the center) come from?**

- Local knowledge
- Expert opinion
- Science (literature, models, simulations)
- Simulation modeling

**Where do the importance-values come from?**

- Individual or group preferences
- Laws and regulations

**Advantages**

- Provides an easy to understand environment for capturing stakeholder interactions
- Cost is minimal (e.g. paper and pencil)
- Can quickly distill the specific areas where stakeholders disagree

**Limitations**

- Impact values can be very hard to agree on
- Importance values can be difficult to establish with polarized stakeholders

### *Advanced Multi-Criteria Decision Making*

#### MAUT – Multi-Attribute Utility Theory

A structured methodology to consider alternative tradeoffs
Uses value functions to create utility

AHP – Analytic Hierarchy Process

Decision maker makes pair-wise determinations
Based on linear algebra
Algorithm puts the information together to make a final determination and explain why
Software -> Expert Choice

**Advantages**

- Considers stakeholder trade-offs at varying levels of consequences
- Can identify inconsistencies in user values
- Can group stakeholder values

**Limitations**

- Can be difficult to understand – easy to mistrust
- Can be time consuming for users
- Does not consider how importance changes with amounts (e.g. decreasing value of a dollar)
- Cannot directly consider
    - spatial relationships
    - temporal relationships
    - indirect and cumulative impacts
    - changes in value with availability of resource

### *Multi-Criteria Decision Making w/ Cumulative Impact*

Consider Figure 7. How can cumulative impacts be added? Add a line for "no action", which will identify the future impacts on the chosen categories without any federal project. Add these values to each of the values from the rows in Figure 7 to create new rows to create Figure 8.

**Example**

| | Recreation | Housing | Attractiveness | Tax base | Jobs | Agriculture | Habitat | Water Quality | Air Quality | Water | Electric | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Importance-> | 10 | 10 | 5 | 18 | 10 | 5 | 9 | 3 | 10 | 10 | 10 | 100 |
| Proposal | | | | | | | | | | | | |
| No action | 0 | 0 | 0 | 5 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | |
| proposal 1 | 3 | 4 | 2 | 5 | 3 | -3 | -10 | -5 | -8 | 3 | 2 | 50 |
| + cum | 3 | 4 | 2 | 10 | 9 | -3 | -10 | -5 | -8 | 3 | 2 | 200 |
| proposal 2 | 10 | 6 | 2 | 5 | 5 | -4 | -6 | -2 | -1 | 4 | 7 | 330 |
| + cum | 10 | 6 | 2 | 10 | 11 | -4 | -6 | -2 | -1 | 4 | 7 | 480 |
| proposal 3 | 5 | 4 | 1 | 10 | 10 | -5 | -2 | -2 | -1 | 3 | 4 | 386 |
| + cum | 5 | 4 | 1 | 15 | 16 | -5 | -2 | -2 | -1 | 3 | 4 | 536 |
| proposal 4 | 8 | 6 | 5 | 5 | 5 | -4 | -8 | -3 | -6 | 1 | 4 | 194 |
| + cum | 8 | 6 | 5 | 10 | 11 | -4 | -8 | -3 | -6 | 1 | 4 | 344 |

**Figure 8: Simple Decision Matrix with Cumulative Impacts**

Note a change in the rank-ordering of alternatives.

## SYSTEMS THINKING

### *Why system thinking?*

- Need to provide impact values to decision matrix!
- World (and any part) is a system.
- Systems in systems in systems …
- Hierarchical scales
- Cause-effect chains (we get distracted with correlations)
- Feedback loops are important (we are not good at working with these)

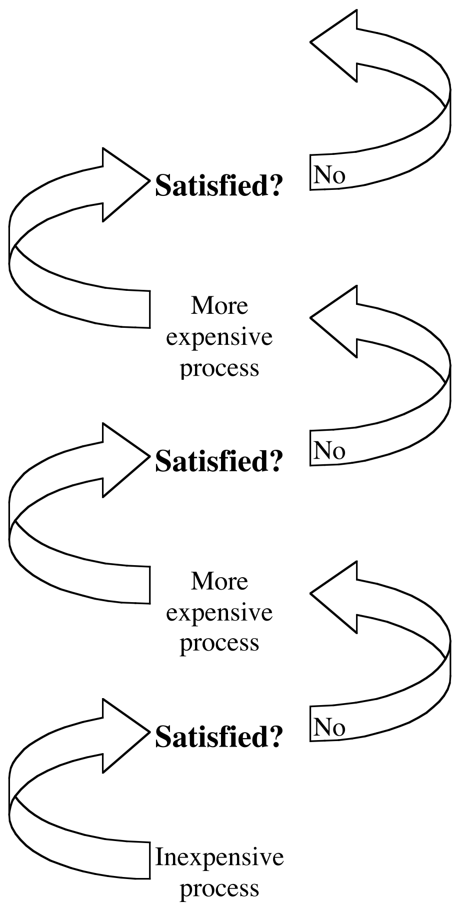
### *Be not afraid – You do systems thinking all the time!*

You have understandings of how the world works. If your model of how an intersection works, you cross the street safely. Otherwise you rework your model – or avoid intersections! If your model of how your spouse thinks is correct you live happily ever after. Otherwise, you are normal and are continually adjusting your model – happily! If your model of a watershed operates is correct, you may be divine.

| *You are already a pro at systems simulation modeling!* |
|---|

### *Who, What, Why, Where, When?*

- Who will be affected?
- What will affect them?
- Why will they be affected?
- Where will the effect happen?
- When will the effect happen?




### *How expensive does the process need to be?*

Point: It's all about getting to a decision

- As quickly as possible
- As inexpensive as possible

**Example**

Question: What will be the depth of water in the lake after a hundred-year storm?

Maximum acceptable depth: 30 ft

Goal: Get an answer that indicates depth will clearly be above or below 30ft.

- Rule of thumb: 20 +/- 9
- Quick and dirty: 32 +/- 5
- Expensive: 31 +/- 1/2

How detailed is necessary here?

Generally, uncertainty decreases with investment (but buyer beware)

Generally, it is useful to start inexpensive and move to more expensive (see Figure 9).

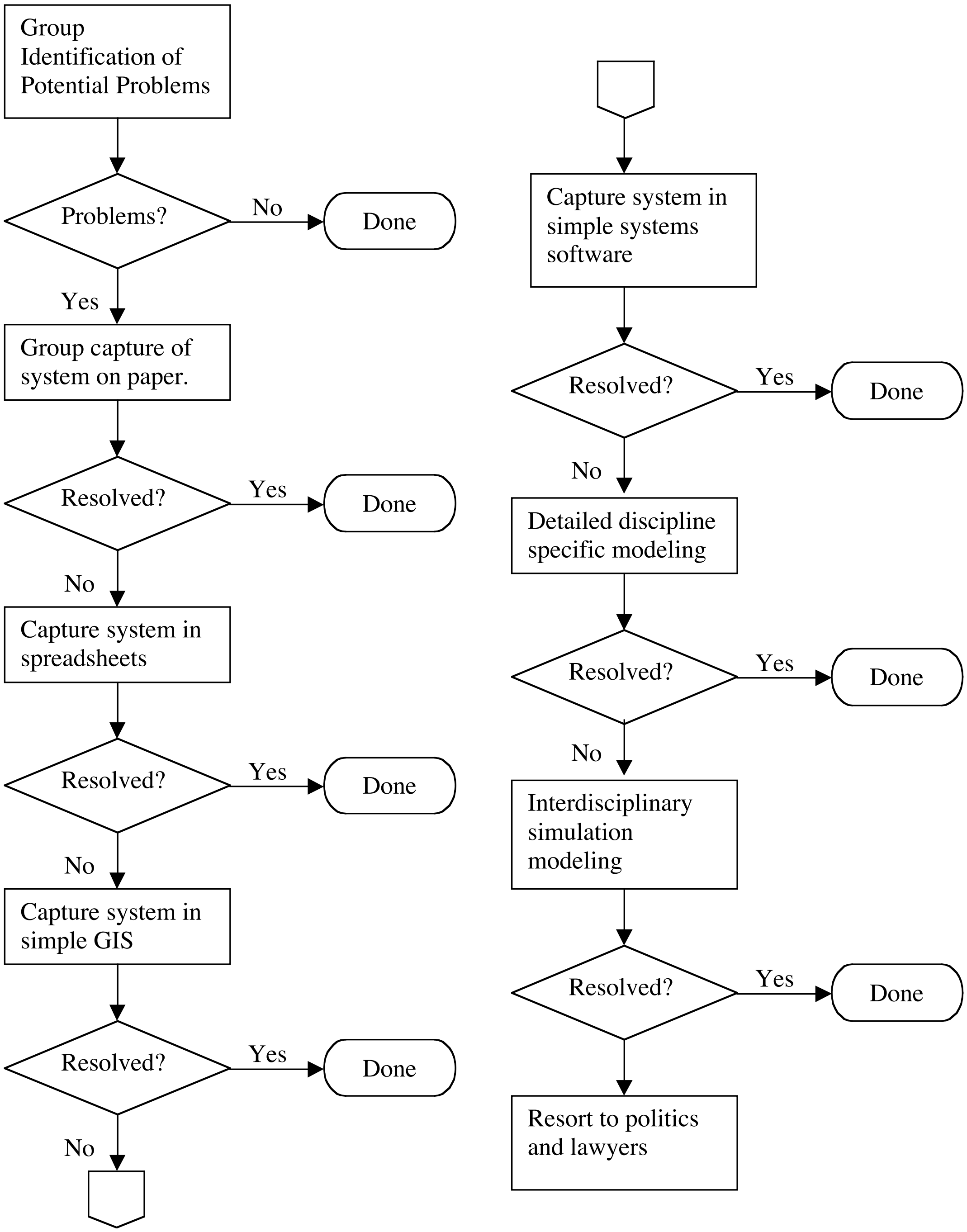



**Figure 9: Decision tree**

### *What level of system hierarchy is appropriate?*

Systems, at least for the purpose of enabling human comprehension, are organized in levels. Consider hierarchical levels in a natural system from highest to lowest:

> Universe, Galaxies, Clusters, Star systems, Planets,
> Continents, Watersheds, Ecosystems,
> Organisms, Organs, Cells, Organelles,
> Molecules, Atoms, Hadrons, Quarks, Strings

*The appropriate level to model is one step below the level being managed – or questioned. Levels above can be considered constant and constraints of the modeling*.

### ***Key pieces of systems thinking***

Stocks: those things (indices) that are tracked through time
Direct cause-effect relationships (can form feedback loops)
Location in time
Location in space
The goal is to describe the behaviors of system components and, through system simulation, elicit behaviors of the system as a whole – emergent behavior.

### ***Questions for discussion***

What factors "scare" us away from simulation modeling?
What traps need to be avoided?
Is more expensive better?
Who understands the whole system?
Is it possible to not be a stakeholder?

# SYSTEMS MODELING WITH LISTS

### *Purpose*

Stakeholder collective basic understanding of the system
Allow all to get concerns recognized – or at least listed
Begin to identify suspected or believed cause-effect relationships

### *Cost-Benefit*

Low cost
Immediate group interaction
High control by a group
Encourages human communication

### *Description*

A stakeholder group is assembled and tasked with identifying proposed and other important actions or activities, impacts of concern, and cause-effect relationships connecting them. Proceed either from the actions or from the impacts and work toward the other. Stick with lists: one impact associated with direct affectors on the impact, or one cause associated with direct impacts. Work very hard to limit the activity to identifying direct cause-effect relationships – avoid correlations and indirect effects. Associate with each item in the list a direction and gross magnitude of the relationship. , For cumulative impact analysis, start with proposed activity, proceed toward impacts, and then work backwards from impacts to identify other activities of concern.

### *Steps*

Identify impacts of concern
Identify proposed actions
Identify other local activities (proposed or on-going) that are suspected of being connected to impacts of concern.
Start with impacts or start with proposed action?
Consider only action -> start with action
Consider impact -> start with impacts
Identify impacts being considered
Place each impact on top of separate page
Under, identify each thing that has a direct affect
Consider each thing as an impact to start a new page
Place –1, -2, -3, 1, 2, 3 value in front of each
Circle each that has solid agreement

### *Exercise*

A highway construction is proposed. Urban growth in the area is anticipated in the area anyhow. Sensitive habitat and threatened species live in the area. There are rumors of a commercial theme park being considered for the area. Municipalities in the region look to broaden tax bases.

1. List impacts of concern to a broad “standard” stakeholder group.
2. Choose one impact and identify things that directly affect it.
   Associate a value between –3 and 3 to each thing indicating the direction and magnitude of the effect on the impact.
3. Identify direct impacts of the proposed construction. Associate a value between –3 and 3 as above.

***Example***

Direct impacts of: <u>Project</u>

Social
- Recreation
- Housing
- Attractiveness

Economic
- Tax base
- Jobs
- Agriculture

Environment
- Habitat
- Water Quality
- Air Quality

Utilities
- Water
- Electric

**Figure 10: Group Listing of Project's Direct Impacts**

***Questions***

Have we captured all of the stakeholder ideas?
Where do we have important disagreement?
Where do we have important uncertainty?
Have any feedback loops been identified?

# SYSTEM MODELING WITH GRAPHICS

### *Purpose*

Identify indirect impacts
Identify feedback loops
Identify cumulative impacts

### *Cost-Benefit*

US culture is familiar with "flow diagrams" – providing a common language
Paper and pencil

### *Description*

Use circles and arrows to graphically capture information on the sheets
Circles represent aspects of the system
Arrows represent cause-effect relationships among the aspects
Dashed arrows represent negative impact, solid represents positive
Width of arrow represents magnitude of impact

### *Example*

Take previous example and recast into this format.
Use overheads/powerpoint
Use large sheet

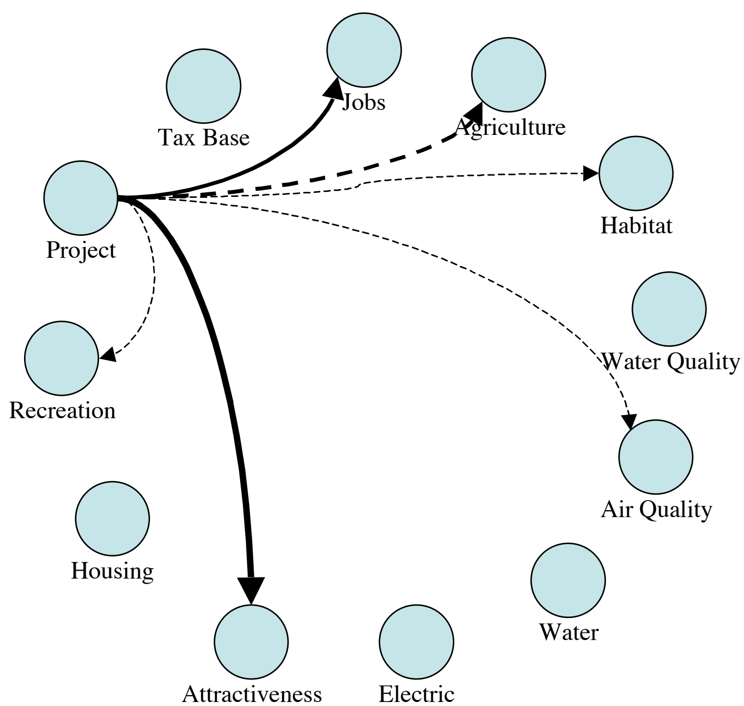



**Figure 11: Capturing system in a flow diagram**

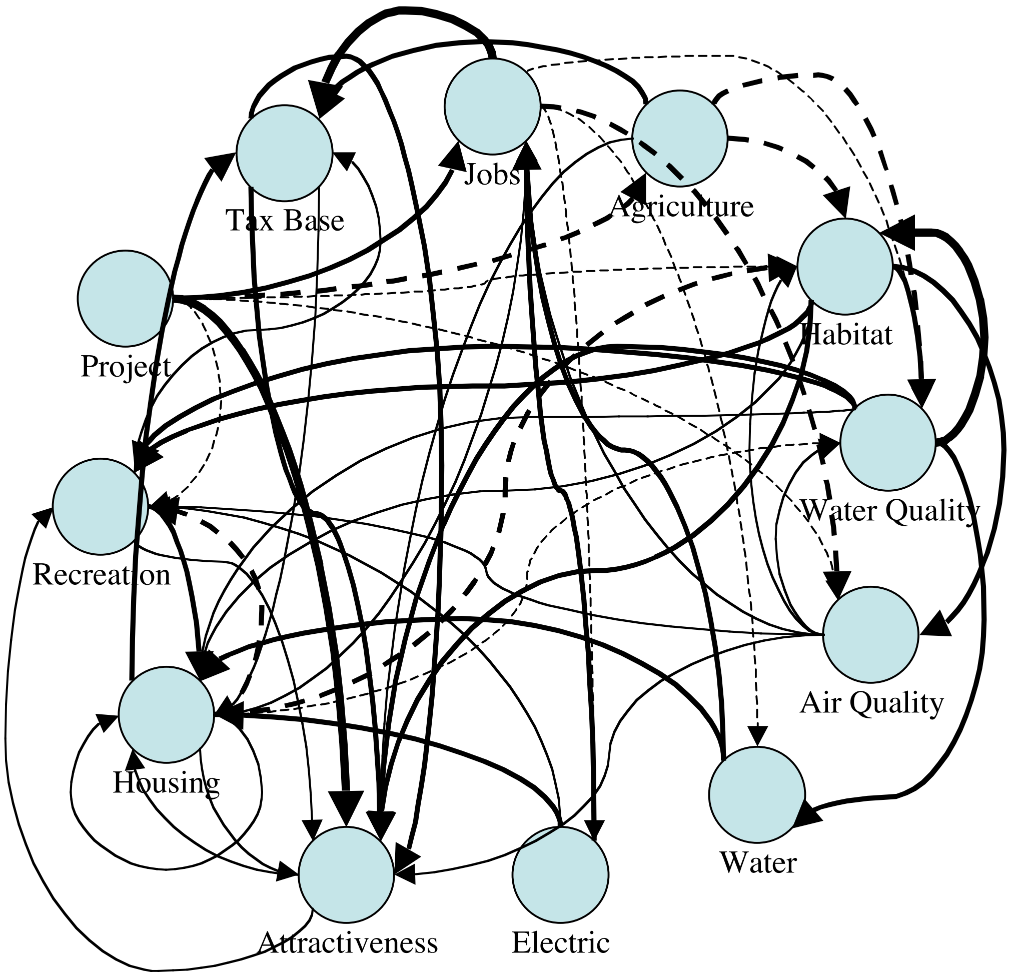



**Figure 12: Capturing the full system in a flow diagram**

### *Questions*

Where are indirect impacts?
Where are feedback loops?
What are the important cumulative impacts?
What can be thrown out?
Where are important uncertainties?
Where are important disagreements?

### *Exercise*

Recast the information from the previous exercise into this format.

# SYSTEMS MODELING WITH A SPREADSHEET

### *Purpose*

Capture across-system cause-effect relationships in one place
Identify indirect impacts
Identify feedback loops
Identify cumulative impacts

### *Cost-Benefit*

Low cost
Computationally easy
Stakeholders can understand
All important information is in one place

### *Approach*

Complete the paper and pencil approach described above
Create 2-D array in a spreadsheet
Place all impacts and actions on X and Y labels
Copy the +s and –s from the sheets into the spreadsheet

### *Example*

| | | | Project | Recreation | Housing | ess | Tax base | Jobs | Agriculture | Habitat | Quality | Air Quality | Water | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | -1 | 0 | 0 | 0 | 2 | -2 | -1 | 0 | -1 | 0 | |
| | Project | 1 | 0 | -1 | 0 | 0 | 0 | 2 | -2 | -1 | 0 | -1 | 0 | |
| SOCIAL | Recreation | | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | Housing | | 0 | -2 | 0 | 1 | 2 | 1 | 0 | -2 | -1 | 0 | 0 | |
| | Attractiveness | | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| ECONOMIC | Tax base | | 0 | 2 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | |
| | Jobs | | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | -1 | -2 | -1 | - |
| | Agriculture | | 0 | 0 | 0 | 1 | 2 | 1 | 0 | -2 | -2 | 1 | 0 | |
| ENVIRONMENT | Habitat | | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | |
| | Water Quality | | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 2 | |
| | Air Quality | | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | |
| UTILITIES | Water | | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | |
| | Electric | | 0 | 1 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | |

Level of direct impact of row item on column items.

**Figure 13: Cause-effect relationships capture in a spreadsheet**

The information from each paper listing of cause-effect relationships are captured in the array. Sheets containing lists of impacts are captured in rows. For example, a sheet containing the direct impact of jobs might have tax base, water quality, air quality, and water as direct impacts. Sheets containing lists of things that affect an impact can be captured as columns. The end result is that lots of information can be captured in a single spreadsheet. The left-most column of numbers represents a change in the system. These can be multiplied by all values in the rest of the row to generate amount of impact on the aspect of the system labeled at the top of each column. Summed, these numbers give the values in the top row of numbers. Hence, the direct impact of the "project" on the system is simply the identified direct impacts – the top two rows of numbers are identical. These numbers can now be placed in the first column of numbers to find out what the first-step indirect impacts of the project are on the system. This can be repeated to capture many multi-step cause-effect chains (Figure 14).

Note how indirect impacts are captured. For example, jobs do not directly affect habitat, but they do affect air quality, which affects habitat. Many such impacts can be found.

### Questions

Where are indirect impacts?
Where are feedback loops?
What are the important cumulative impacts?
What can be thrown out?

### Exercise

***Begin entering in the information captured in the previous exercise into the form below:***

| | | ***Highway project*** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ***0*** | | | | | | | | | |
| ***Highway project*** | ***1*** | ***0*** | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
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| | | | | | | | | | | | |

| | | | Project | Recreation | Housing | Attractiveness | Tax base | Jobs | Agriculture | Habitat | Water Quality | Air Quality | Water | Electric |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | -1 | 0 | 0 | 0 | 2 | -2 | -1 | 0 | -1 | 0 | 0 |
| | Project | 1 | 0 | -1 | 0 | 0 | 0 | 2 | -2 | -1 | 0 | -1 | 0 | 0 |
| SOCIAL | Recreation | | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Housing | | 0 | -2 | 0 | 1 | 2 | 1 | 0 | -2 | -1 | 0 | 0 | 0 |
| | Attractiveness | | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ECONOMIC | Tax base | | 0 | 2 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Jobs | | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | -1 | -2 | -1 | -1 |
| | Agriculture | | 0 | 0 | 0 | 1 | 2 | 1 | 0 | -2 | -2 | 1 | 0 | 0 |
| ENVIRONMENT | Habitat | | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 |
| | Water Quality | | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 2 | 0 |
| | Air Quality | | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| UTILITIES | Water | | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Electric | | 0 | 1 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | Project | Recreation | Housing | Attractiveness | Tax base | Jobs | Agriculture | Habitat | Water Quality | Air Quality | Water | Electric |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | -3 | -3 | -6 | 1 | -3 | 0 | 3 | -1 | -8 | -2 | -2 |
| | Project | 0 | 0 | -1 | 0 | 0 | 0 | 2 | -2 | -1 | 0 | -1 | 0 | 0 |
| SOCIAL | Recreation | -1 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Housing | 0 | 0 | -2 | 0 | 1 | 2 | 1 | 0 | -2 | -1 | 0 | 0 | 0 |
| | Attractiveness | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ECONOMIC | Tax base | 0 | 0 | 2 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Jobs | 2 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | -1 | -2 | -1 | -1 |
| | Agriculture | -2 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | -2 | -2 | 1 | 0 | 0 |
| ENVIRONMENT | Habitat | -1 | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 |
| | Water Quality | 0 | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 2 | 0 |
| | Air Quality | -1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| UTILITIES | Water | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Electric | 0 | 0 | 1 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | Project | Recreation | Housing | Attractiveness | Tax base | Jobs | Agriculture | Habitat | Water Quality | Air Quality | Water | Electric |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | -4 | # | -8 | # | # | 0 | -5 | 4 | 12 | 1 | 3 |
| | Project | 0 | 0 | -1 | 0 | 0 | 0 | 2 | -2 | -1 | 0 | -1 | 0 | 0 |
| SOCIAL | Recreation | -3 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Housing | -3 | 0 | -2 | 0 | 1 | 2 | 1 | 0 | -2 | -1 | 0 | 0 | 0 |
| | Attractiveness | -6 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ECONOMIC | Tax base | 1 | 0 | 2 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Jobs | -3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | -1 | -2 | -1 | -1 |
| | Agriculture | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | -2 | -2 | 1 | 0 | 0 |
| ENVIRONMENT | Habitat | 3 | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 |
| | Water Quality | -1 | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 2 | 0 |
| | Air Quality | -8 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| UTILITIES | Water | -2 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Electric | -2 | 0 | 1 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 14: Input/output "cycles"

# TIME AND SPACE

### *Purpose*

Seek to break cause-effect relationships.

### *Cost-Benefit*

Location requires maps/GIS
Time requires tapping into science of climate, atmosphere, ecology, hydrology
Benefit: find breaks cause-effect

### *Description*

Develop GIS maps to indicate location of activities and impacts
Separate maps for different times of the year or times of day
Overlay causes and affects to identify overlap

### *Example*

GIS overlays
Refer back to cause-effect diagrams developed/presented above

### *Questions*

Possible to reduce uncertainty on cause-effect links?
Possible to gain group consensus?
Where do important uncertainties remain?
Where do important disagreements remain?

# GIS – Geographic Information Systems

### *Purpose*
Communication tool.
Conduct spatially explicit analyses.
Identify where activity locations and impact locations are – test for coincidence
Identify when activities and potential impacts occur – test for coincidence
Develop inputs for spatially explicit simulation modeling

### *Cost-Benefit*
Significant investment in software, hardware, data, and expertise.

### *Description*
GIS activities can be from novice to extremely advanced; analysis stages:

1. "Pretty pictures" (Cartography)
    - Single map
    - Pick and choose themes
    - Choose colors
    - Add text, legend, scale, north arrow
2. Data input and alignment
3. Professional presentation
4. Analyses
    - Distance, buffer, grow, slope/aspect
5. Advanced analyses
    - Flow, least cost path, clump, neighborhood analysis, patch, spatial statistics, covariance analysis, fast fourier transformations, sun shading, hydrology, map algebra, volume, centroid, coincident, image processsing
6. Simulations
    - Hydrology, fire

Primary Data

1. Digital elevation models (DEM)
2. Digital orthophotos
3. Property boundaries
4. Land use / land cover

### *Example*
Visualizations

- Single map
- Multiple map
- 3-d displays
- Fly-throughs
- Cartographic quality
- Slice-throughs
- Zoom/Pan

Data input

- Paper map digitizing
- On-screen digitizing
- Scanning and automated detection
- Image processing

  - Maximum liklihood classifier
  - Many band-ratios
- GPS (on-ground digitizing)

What can I do with a digital ortho photo?

- Visualize
- Digitize
  - Roads, buildings, forests, lines

What can I do with a DEM?

- Slope
- Elevation
- Watershed boundaries
- Flow direction
- Flow accumulation
- Slope-length
- Shade relief
- Identify basins

Find all the areas that have these characteristics …

- !/2 mile to 1 mile from a main road
- 5% slope
- View of 25% of land within 10 miles
- Forested
- Within 2 miles of a sailing lake

### *Questions*

Show me a map with …
Let me zoom and pan
Let me print maps
Does the impact occur where the sensitive area is?
Does the impact occur when the sensitive area is sensitive?

### *Exercise*

List some of the most amazing things you've ever seen done with GIS.

# SYSTEM SIMULATION MODELING

### *Purpose*

Test system responses to proposed actions
Help better isolate the essential aspects of the system and the actual and important connections

### *Cost-Benefit*

Expensive, time consuming
Black-box
Capture knowledge of system dynamics
Can be data intensive
Can be process based
Many levels (i.e. world to atoms)
Best run by those who know model details
Calibration often difficult/expensive
Multiple-models useful for cross-calibration

### *Description*

Levels of complexity
Discipline specific
Open ended
Stella

### *Example*

Capture above example into Stella – or similar software

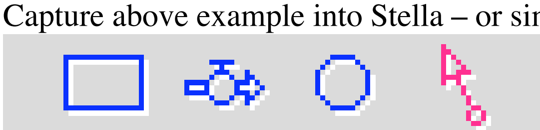

**Figure 15: Primary Stella Icons**

The primary graphic icons used in Stella to capture systems are displayed in Figure 15. First, the rectangle is used to represent a system stock – a value that represents part of the state of the system. These are things like reservoir level, population size, or concentration of a chemical. The second symbol is used to capture "flows" into and out of stocks and is the only mechanism by which stock values can change. Graphically, think of this symbol as a pipe with flow going in the direction of the value, with an attached valve – it is an outdoor water faucet. The third icon is called a converter. It is associated with fixed values or equations. The last allows you to connect the pieces to identify cause-effect relationships.
Consider a simple system represented in Figure 16. The only stock in the system is "Population" and the flows to "fill" and "drain" it are "Birth" and "Death". The number of deaths in each time step is a function of only "Population". The number of births is a function of "Population" and "Birth Rate". Finally, "Birth Rate" is a function of "Population" and "Max Birth Rate". At this stage we have a conceptual model represented only graphically.

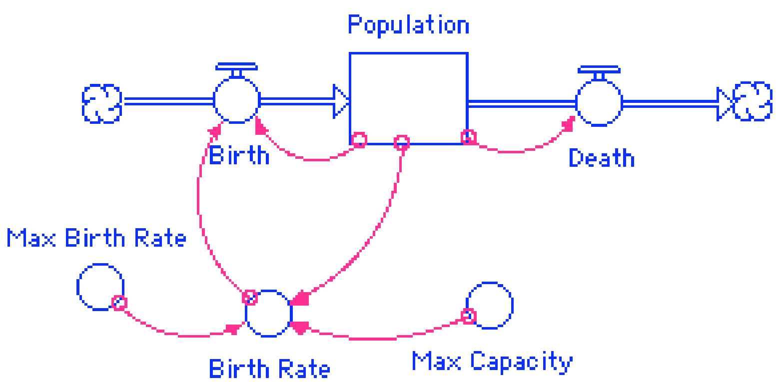


**Figure 16: A simple Stella model**

To complete, we must identify the starting "Population" size, the "Max Birth Rate", and equations using the values associated with the arrows for the "Birth" and "Death" flows and the "Birth Rate" converter. Run output in Figure 17 results from the following values and equations:

Population(t) = Population(t - dt) + (Birth - Death) * dt
Population = 10
Birth = Population*Birth_Rate
Death = .01*Population
Birth_Rate = Max_Birth_Rate*(Max_Capacity-Population)/Max_Capacity
Max_Birth_Rate = .1
Max_Capacity = 1000

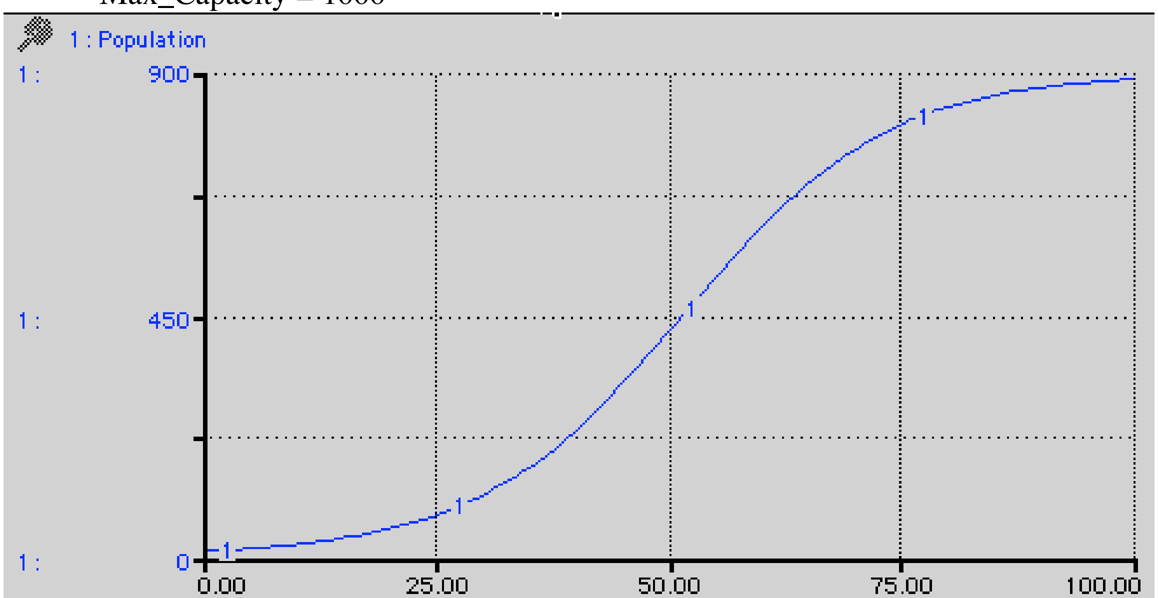


**Figure 17: Sample simulation run**

Our sample model can be captured in the Stella environment. The dashed stocks at the left are "ghosts" of the stocks on the right; this allows us to avoid creating more spaghetti. Note that unlike our diagram of the system in Figure 12, some of our system components are captured as stocks (rectangles) and others as converters (circles). Generally, those components that are basic, measurable parts are stocks, while those that can be predicted from these stocks are converters.

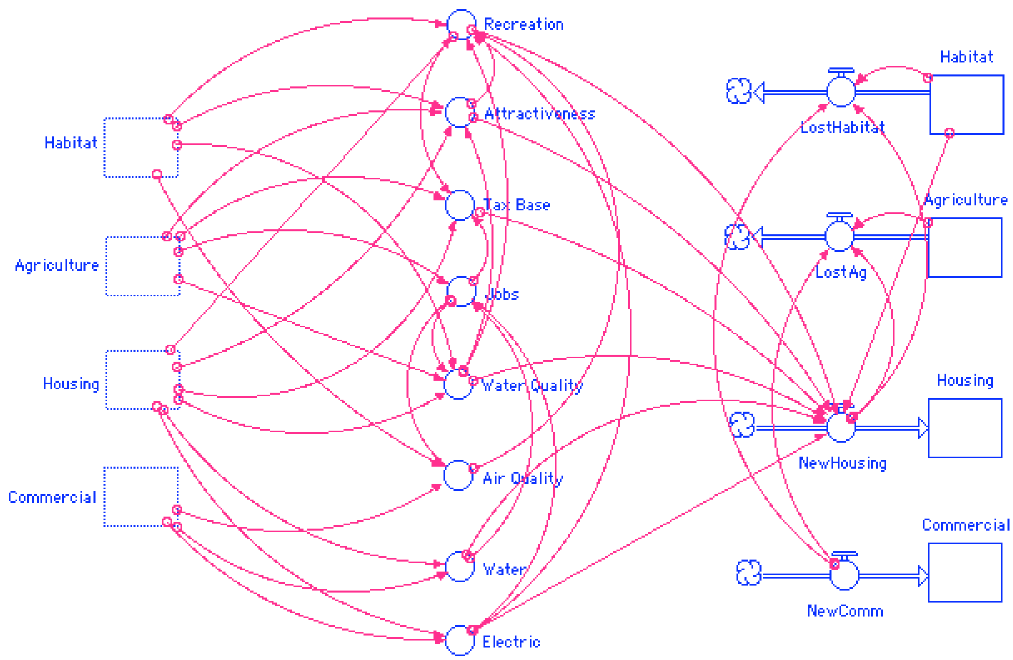


**Figure 18: Sample model in Stella**

Close inspection of this model, in comparison with our other representations of the system, yields some slight, but significant differences. In Stella, feedback loops must include a flow-stock combination. This restricts feedback loops from being fully completed in a single time step.

### *Questions*

What happens when I make my system "come alive" – add dynamic behaviors to my system?

### *Exercise*

Identify from the previous exercise the system aspects that would be captured as stocks. Why?

# DETAILED DISCIPLINE SPECIFIC SIM MODELING

### *Purpose*

Capture "all" of the science associated with a part of the system

### *Cost-Benefit*

Cost high for already developed models
Cost very high for models developed "from scratch"
Very hard to choose from among models
Little, if any, connection to the full system

### *Description*

Western science is fundamentally divided into disciplines – tremendous progress has been made to understand our natural systems as essentially divided pieces. We are collectively excellent at "splitting" and rewarding the progress made in so doing. We are less effective at "clumping" – putting the pieces back together and understanding the larger system holistically. Excellent simulation models have thus been developed that capture discipline-centric understandings of the pieces.

### *Examples*

- Surface water erosion and pollution
- River management
- Stream management
- Plant Community Succession
- Urban Growth

See Appendix C.

### *Questions*

What do models that scientists have built tell us about our system?
Where will water flow? How deep will it be? How far will the flood extend?
What will be growing here in a few decades?
How much water needs to pass a lock and dam system in the next day?
Where will urban growth likely occur?
What will the chemical concentrations be in my soils and streams?

### *Hydrology*

A number of representative models, divided into the following categories, are briefly reviewed. This review provides a sense of the scope and depth of hydrologic simulation models developed to understand and predict hydrologic behavior of and within watersheds.

- Field-scale Hydrologic and Soil Erosion Models
- Watershed-scale Hydrologic and Soil Erosion Models
- Groundwater Models
- Field-scale Water Quality Models
- Watershed-scale Water Quality Models

#### Field Scale Hydrologic and Soil Erosion Models

Field-scale models treat entire fields as single, discrete, and homogeneous entities. These models are typically simple enough to state, but difficult to parameterize, which can often result in a handbook with a simple equation followed by many pages of look-up parameters. When a field does contain a single dominant soil type, has a constant slope and aspect, and a single management history, these models are quick and efficient. Field-scale hydrology models have been developed to predict anticipated farm field erosion based on weather, climate, field conditions, crop, soil type or qualities, and topography. While these models have been developed to assist in the management of farm and grazing lands, this management occurs in the context of watersheds and the models can be useful beyond the farm. Before computers could be applied, it was necessary to develop and adopt simple equations that could be used by farmers and land managers. One such model is the "rational method". It calculates the peak runoff rate as follows:

$$Q = 0.002CiA$$

Q is the peak runoff rate, C is a dimensionless runoff coefficient, i is the rainfall intensity, and A is the watershed area in hectares (ha). This equation has many assumptions including steady-state watershed outlet flow due to constant rainfall in time and space over the watershed. It also assumes no infiltration. Finally, the equation does not predict the time of peak flow nor any other part of a hydrograph's structure.

Another simply structured equation developed in the mid-part of the 20th century is the Universal Soil-Loss Equation (USLE) and the updated Revised Universal Soil-Loss Equation (RUSLE) (Wischmeier and Smith 1978). For both, the form of the equation for predicting field soil loss is identical:

$A = RK(LS)CP$

where:

A – the predicted average annual soil loss
R – index for the local rain dislodgment of soil and the movement of soil in runoff
K – factor for the soil erodability
LS – factor for the slope and length of the slope
C – factor for the crop cover
P – factor for conservation practices

A number of indices reflecting rainfall erosivity, soil erodability, slope-length, steepness, cover, and conservation practices are identified for the location of interest and multiplied together to estimate the average annual soil loss. Indices have been developed through many years of experimentation and trials. By using look-up tables, one can readily apply this simple model to an area to calculate average annual soil loss. Some limitations of the model were overcome with the introduction of the RUSLE, which includes modern Windows-based user interfaces that allow for automatic table look-up based on user specification of slope, soil types, crop cover, and location. RUSLE and USLE parameters were developed over many decades of measurements followed by statistical analyses. Limitations include the need for erosion studies when different soil types and crop covers are encountered. And, while sheet and rill erosion is considered, erosion associated with gullies (created when rills converge) is not estimated. These limitations are addressed through the development of process-based models and through the application of geographic information systems (GIS).

The USLE/RUSLE presume that the area under consideration is relatively homogeneous with a constant slope and aspect and containing a single soil type, land cover, and conservation practice. Moving to larger parcels eventually ensures that the terrain is complex over space,  and over time. If a complex landscape is divided into smaller parcels and those parcels are hydrologically connected, then the USLE/RUSLE analyses can be completed for each parcel. Systems like the Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS) model (Beasley and Huggins 1982) and Agricultural Non-Point Source Pollution (AGNPS [1]) Model (Young, Onstad et al. 1989) provide this approach. These models still use the various experimentally derived USLE/RUSLE indicies and factors. A next step is to develop physics-based process models that can be applied to any area where the physical properties and components of the soil are known. Spatially explicit process-oriented erosion simulation models include, Cascade—2D CASC2D (Saghafian

[1] AGNPS - http://www.cee.odu.edu/cee/model/agnps_desc.html

1993), the Water Erosion Prediction Project (WEPP[2]) model, and the Simulation of Watershed Erosion (SIMWE) (Mitasova, Mitas et al. 1998). These are process-based distributed parameter models that run in conjunction with digital map inputs. The inputs include topographic information like slope and elevation, soil qualities, crop cover, weather information including synthetic or recorded storms, and field treatment schedules. The physical processes involved when rain dislodges soil and when sheet, rill, and stream flow moves dislodged particles are modeled. Pure physical process-based models can be run to develop the USLE/RUSLE model parameters on areas that have not been studied. Information about the soil structure, such as percent sand, clay, loam, and organic matter is typically required. These models are computationally intensive and have become useful only recently with the cheap availability of fast computers.

As we moved through this list from the experimental and statistically based USLE/RUSLE to the process-based models, the computational requirements increase dramatically. Adoption of spatially explicit modeling becomes important for complex terrains in which the topography, cover, and/or treatment varies. Adoption of process-based modeling allows us to simulate complex terrains without requiring that indicies and factors be pre-established. Process-based modeling requires the application of powerful (but now inexpensive) computers, while the USLE/RUSLE approaches can be accomplished with a handbook, pencil, and paper. The more complex models will continue to become increasingly cost-effective as the models and model input data become easier to acquire and use.

## Watershed- Scale Hydrologic and Soil Erosion Models

Within a watershed there can be hundreds of separate fields. If those fields can be appropriately modeled with field-scale models, it should be possible to describe the watershed processes by combining all of the field models. While it is possible to model larger watersheds using field-scale simulation models, the data requirements can become overwhelming. Complex terrains are very difficult to model with field-scale models and combining a large number of fields in such a terrain is not likely to yield useful information about the watershed as a whole. It has traditionally been popular to model watersheds as whole entities. These watershed-level models are more frequently built up from lumped-parameter models of subwatershed components. TR-20, developed by the Soil Conservation Service, and HEC-1, developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center are two such models. The hydrologic response of subwatershed components (overland flow areas and stream/river segments) are defined and connected to allow for full watershed hydrologic responses. These programs were developed at a time when input data was provided through punch cards and, today, the programs require input provided via card images in computer files. A modern user interface has been developed for the Watershed Modeling System (WMS)[3] that automates the development of the card image files through automatic interactions of watershed information stored in GIS data files. Lumped-parameter models require that each watershed subcomponent be characterized with a set of numbers representing its general or cumulative nature. Systems like the WMS query raster and vector GIS data to automatically generate the lumped parameters for each of the subwatersheds and associated streams and rivers. Users can still be responsible for identifying detailed stream/river cross-section information. Recently, the Hydrologic Engineering Center released a new product intended to supercede HEC-1 called HEC-HMS[4] (Hydrologic Modeling System). A modern graphical user interface and standard database system has been fully integrated into the modeling system.

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[2] WEPP - http://topsoil.nserl.purdue.edu/weppmain/wepp.html

[3] Watershed Modeling System - http://ripple.wes.army.mil/software

[4] Hydrologic Modeling System - http://www.hec.usace.army.mil

## Groundwater Models

Like watershed-scale models, groundwater models were originally developed for computers that took input through computer cards. Many of these historic models are finding new life in integrated systems that run on modern desktop and workstation computers. An excellent example of such a system is the Army Corps of Engineers' Groundwater Modeling System[5] (GMS). A number of models have been combined and incorporated into this system (Owen, Jones et al.) MODFLOW[6] partitions a subsurface area into discrete three-dimensional chunks that are each defined by location and soil characteristics. Water flows are routed through this space. MODPATH[7] routes particles through this space. SEEP2D assists in the modeling of water flow under and through dams and levees. A number of pollutant movement and tracking models (see below) are associated with the water movement model.

## Field-Scale Water Quality Models

Hydrologic models route water over and through the ground. Water movement facilitates the transport of various chemicals — some of which influence water quality. Many water quality models have been developed for field-scale settings that are concerned with the movement of nitrogen, phosphorous, potassium, and various organic herbicides and pesticides. The Root Zone Water Quality Model (RZWQM) simulates the movement of water and associated chemicals in the vertical direction as part of an integrated crop growth modeling system[8]. The Ground Water Loading Effects of Agricultural Management Systems (GLEAMS), the Erosion/Productivity Impact Calculator (EPIC), and the Chemical, Runoff, and Erosion from Agricultural Management Systems (CREAMS) are examples of coupled 2-D field-level simulation models for predicting chemical transport. Discussions about and availability of these and other models are can be found at a National Resources Conservation Service Internet site[9].

## Watershed-Scale Water Quality Models

Movement of water, soils, and chemicals is of course also modeled for larger watershed systems. Different systems predict water quality in urban and rural watersheds. In the GMS (Owen, Jones et al. ) a number of models (MT3D, RT3D, and FEMWATER) simulate the movement of contaminates through the groundwater. The Water Quality Analysis Simulation Program (WASP), a DOS program developed by the EPA, combines a number of other models that simulate, hydrodynamics, unsteady flow in one-dimensional rivers, unsteady, three-dimensional flow in lakes and estuaries, conventional pollution (involving dissolved oxygen, biochemical oxygen demand, nutrients, and eutrophication), and toxic pollution (involving organic chemicals, metals, and sediment). The EPA's Storm Water Management Model (SWMM) is similarly DOS-based with a long development history that includes a number of modern Windows interfaces[10]. It models single event and continuous watershed water quality simulation primarily, but not exclusively, for urban watersheds.

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[5] Groundwater Modeling System - http://www.hec.usace.army.mil

[6] MODFLOW - http://water.usgs.gov/software/modflow-88.html

[7] MODPATH - http://water.usgs.gov/software/modpath.html

[8] RZWQM - http://www.gpsr.colostate.edu/GPSR/products/rzwqm.htm

[9] Water, Field Scale and Watershed Scale Computer Models, Field and/or Point Assessment Tools, and Tools Under Development - http://www.wcc.nrcs.usda.gov/water/quality/common/h2oqual.html

[10] SWMM - http://www.epa.gov/SWMM_WINDOWS

The Soil and Water Assessment Tool (SWAT) is a public domain product under active development at the Agricultural Research Service's Grassland, Soil, and Water Research Laboratory (Temple, TX). SWAT employs a modern Windows interface to an integrated system of models and GIS that routes water and chemicals through surface flow, groundwater flow, and stream/river flow, and can be applied to watershed basins of several thousand square miles[11].

The Hydrologic Simulation Program — FORTRAN (HSPF) is a comprehensive modeling set that simulates the movement of pollutants (conventional and toxic) through land/soil runoff processes linked directly to in-stream chemical and hydraulic processes[12]. Model output includes flow rates, chemical concentrations, and sediment loads.

All of the models listed thusfar require an operator trained in hydrologic modeling and comfortable building input files in a DOS environment. Although the modeling equations are all captured in software, the parameterization of the model and data collection for a particular location can be arduous. This makes virtually all of the models inaccessible to watershed planning groups except through the expertise of water quality and hydrologic engineers. EPA has worked very hard to create a watershed water quality modeling environment that is accessible to more people. The system is called Better Assessment Science Integrating Point and Nonpoint Sources[13] (BASINS). This system is based directly on the commercial GIS, ArcView, and its native user interface and programming language, Avenue. Through Internet connection or CD-ROM, users access not only the set of programs, but preformatted GIS data required to run the model. Virtually any watershed in the United States can be modeled using readily available and preformatted data. Users are also provided tools and instructions for updating the data to reflect local policy and construction changes. BASINS offers a nonpoint source model (NPSM), which is a user interface combined with HSPF (see above). It uses QUAL2E for steady-state water quality and eutrophication modeling and TOXIROUTE for simple dilution/decay of pollutants for screening purposes. The ArcView-based user interface makes the model accessible by individuals familiar with the ArcView GIS environment as well as hydrologists.

### Ecology

Applied Biomathematics supports the RAMAS series of ecological software.[14] Community- and population-based simulation modeling has been supported since the mid 1980s. Metapopulation simulation models allow resource managers to evaluate the importance of interbreeding between two or more populations separated by space. Recently, spatially explicit simulation has been supported in the RAMAS GIS package. Habitat suitability (HS) models are applied to information stored in raster GIS data layers. The resulting suitability maps are automatically analyzed to identify habitat patches that are then fed automatically into the standard RAMAS community and population modeling models. This software is founded on metapopulation and patch theory discussed earlier in this chapter (Whigham and Davis 1989; Buckley, Coughenour et al. 1993; Cuddy 1993)

### Forestry

Simulation of ecological processes at the level of the landscape has also resulted in a significant number of models and modeling approaches. Forest ecologists have been very productive in this area, producing a number of modeling environments. An example is the JABOWA model (Botkin, Janak et al. 1972; Botkin 1977). It is an individual-based model that tracks the growth of trees and their effects on their neighbors within a small area

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[11] SWAT main page - http://www.brc.tamus.edu/swat

[12] HSPF - ftp://ftp.epa.gov/epa_ceam/wwwhtml/hspf.htm

[13] BASINS - http://www.epa.gov/OST/BASINS

[14] RAMAS Ecological Software - http://www.ramas.com

(about 10 meters square). The loss of large trees within such an area leaves a gap in the forest canopy. More recent versions of gap models simulate a large number of "gaps" that match cells in a raster GIS. One such model is ZELIG; a dynamic simulation environment that divides landscapes into cells divided into gap-scale plots (Urban, Bonan et al. 1991). The plots are identified with the proportion of total area in different cover types. Another example is LANDIS, a JABOWA/FORET model simultaneously run for each cell in a large raster matrix. LANDIS was developed by Mladenhoff, Host, and Broeder (Mladenhoff, Host et al. 1993). Individual trees are modeled as part of cells that consider the size, location, type, and state of all member trees. Models in neighboring cells are allowed to dynamically affect each other using this approach.

A large number of modeling approaches, based on patch theory (section 2.1.4), are represented by the following examples. PatchMod is (1) a spatially explicit age and size-structured patch demographic model and (2) a multiple species plant population dynamic model. PatchMod was used to model the Jasper Ridge serpentine grassland; gopher mounds provide the primary patch-generating disturbance (Wu 1994). The ARC/INFO GIS and a FORTRAN-based ecosystem landscape model were combined through an ecological modeling interface to address vegetation and ungulate management objectives. The natural system is broken down, for model development purposes, into twelve primary submodels (Buckley, Coughenour et al. 1993).

# INTERDISCIPLINARY SYSTEM SIMULATION MODELING

### *Purpose*

Ideally, create a working model of interactions among system components that best capture feedback loops

### *Cost-Benefit*

Typically, very expensive.
Can take too long.
With high stakeholder interest, may be ignored for lack of understanding.
Every application is new because the most important aspects of systems vary from location to location and problem to problem.
Benefit is a best capturing of the local system.
Very difficult to simultaneously calibrate all model components.

### *Description*

Interdisciplinary simulation models are developed in two different ways:

1. From “scratch” within a simulation modeling environment
2. By piecing together existing discipline-centric simulation models

The first approach has the advantage of allowing substantial freedom in the capturing of the specifics of the local system. The second allows use of already developed and tested code. In both cases many months (and often years) of development is necessary requiring the close collaboration of a multidisciplinary team that involves talented software developers.

### *Example*

EPA’s MIMS (Multi-media Integrated Modeling System) An interdisciplinary simulation model that links climate, air quality, weather, hydrology, vegetation, ocean currents, and health of ocean organisms. It was built upon the DIAS modeling environment (covered later).

### *Questions*

What are the direct and indirect consequences of actions?
If I put in a highway, what will be the long-term impacts on regional hydrology?
… on sensitive habitats?
… on urban patterns?
… on the local economy?
… on the regional tax base?

## SIMULATION MODEL DEVELOPMENT ENVIRONMENTS

### *DIAS*

DIAS, the Dynamic Information Architecture System[15], is a powerful software environment developed by and for the Decision and Information Sciences Division at Argonne National Laboratory. This environment was developed precisely to facilitate a solution to the challenge of linking disparate multi disciplinary simulation models. DIAS allows software engineers to write simulation models that, at run-time, communicate with modified versions of legacy simulation models. The communication is two-way, which means that through DIAS, the different running models can exchange watershed state information with one another. DIAS was initially developed in support of a Dynamic Environmental Effects Model[16] (DEEM) funded by the Defense Modeling and Simulation Office (DMSO). DIAS has numerous support capabilities that accept data from various GIS and DBMS (database management system) formats, has a built-in object-oriented GIS, and many internal simulation models. DIAS provides the software "glue" to hold together any number of discipline-specific environmental, economic, and social models useful in watershed modeling.

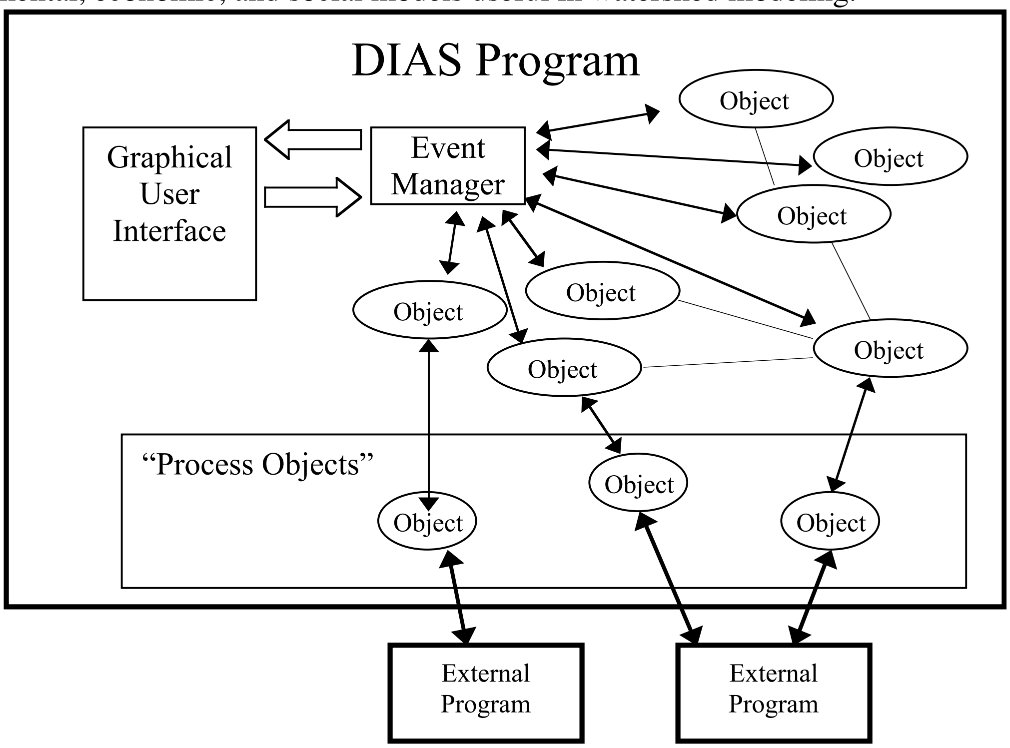


**Figure 19: A conceptual representation of the DIAS environment**

In Figure 19, the one large and two small rectangles represent separately running processes. The large rectangle represents a core DIAS program. In this program, the "Event Manager" communicates with all of the model's objects (represented by the word "object" inside large ovals. These objects are DIAS compliant and are selected by a modeler from a "Frame Toolkit's" Object Library. The objects may contain all of the software code required for representing an aspect of the process being modeled. Alternately, they may accomplish their simulation modeling requirements by passing requests to "Process Objects", which make calls to computer programs (the small "External Program" rectangles) running simultaneously in parallel. Such programs are typically scientific models that were originally developed as stand-alone simulation models. By encapsulating

[15] DIAS - http://www.dis.anl.gov/DIAS

[16] DEEM - http://www.dis.anl.gov/DEEM/

the simulation software associated with these models with a layer of software that supports inter-process communication to the "Process Objects", the former stand-alone models can participate in a multi disciplinary simulation model. For efficiency, most additions to the growing DIAS library are written directly as internal DIAS simulation objects. The DIAS software represents a powerful and ingenious approach to the integration of multi disciplinary simulation modeling that will be necessary to fully use scientific models in watershed management decision processes.

### *SME*

From a software engineering approach, getting disparate simulation models to interact with one another is best accomplished by building the simulation models within a pre-defined framework. An excellent example of this approach is the Spatial Modeling Environment[17] (SME). Figure 20 outlines the process for model development. None of the steps in this process involved writing computer programs, in the traditional sense. The patch-based submodels were developed using a dynamic simulation modeling software environment called Stella in step 1. (The Stella[18] modeling environment is an example of a commercial product that makes it easy to specify simulation models through the development of algebraic and logic equations that describes how a system changes between time steps.) Step 2 involved the automatic conversion of the Stella-generated equations into C++ computer language using the Spatial Modeling Environment (SME). The resulting software arranges for the Stella-developed model to be run simultaneously within each landscape patch. To initialize the state of the system in these patches, GIS database development and analysis was conducted as needed (step 4). At run-time (step 5) these data layers were read into memory and the Stella equations were applied repetitively (for each time step) resulting in landscape state changes over time that could be captured as map output and as tables.

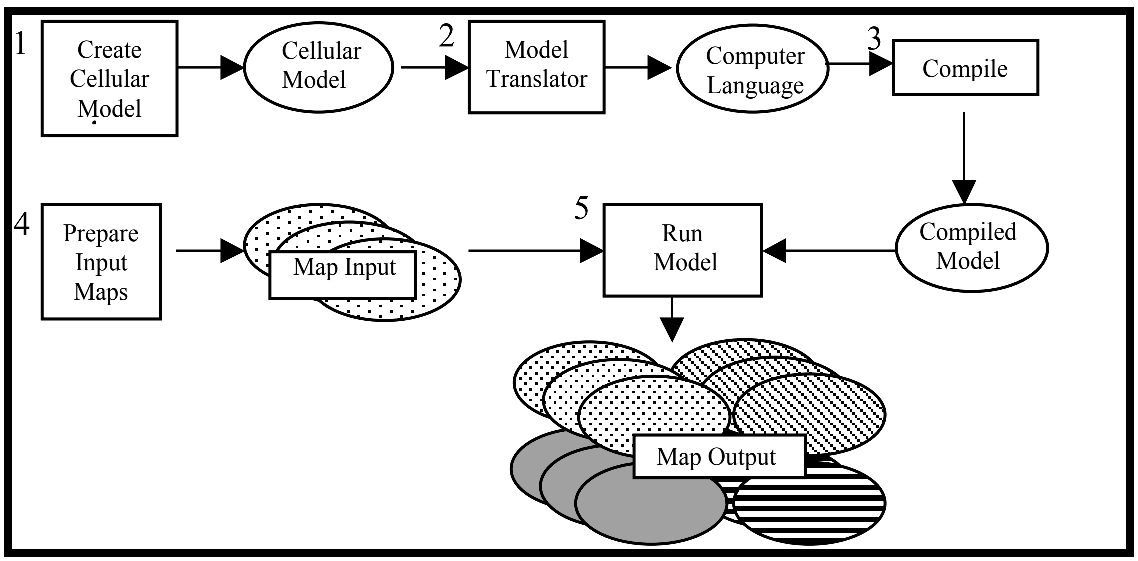


**Figure 20: The Stella/SME model development process**

Step 2 results in a simulation model module that can be added to a local library of simulation modules. A goal of the SME developer is to facilitate the development of modules within local libraries that can be easily shared with other SME users. Sharing can be very practical when developing new capabilities for which the software was designed. Recasting large legacy models in this environment is impractical however.

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17 SME - http://kabir.cbl.umces.edu/SME3/

18 High Performance Systems, Inc - http://www.hps-inc.com/

# SIMULATION MODEL DEVELOPMENT STEPS

### *1) Identify Objectives and Constraints*

Identify the End User

- Characterize the end user
- What decisions will be made?
- How accurate do the output requirements need to be?
- How much funding is available for the effort?

Identify the available resources

- What data is available?
- What expertise is available?
- What applicable models already exist for the system under consideration?

Identify tool availability

- What computer hardware is available?
- What software capabilities are available?
- What costs and benefits are incurred in hardware/software use?

Consider the **level of effort** possible

- How much time can each participant provide to the effort?
- What time frames are available for inter-team coordination?

### *2) Develop Overall Modeling Constraint Decisions*

Identify potential model components

- Watershed patches.
- Linear objects.
- Discrete, mobile objects.

Identify potential model interactions

- Raster GIS interactions
  - Simple location-by-location overlays
  - Near neighborhood operations
  - Cellular automata interactions
  - Vector GIS interactions
  - Interactions between mobile objects

Time Frame

Time Step Considerations

- Fixed
- Variable
- Event driven

Spatial Resolution

- Fixed
- Hierarchical

- Variable

***3) Conceptualize Full Model***

1. Identified subcomponents of the desired full model.
2. Inputs required by each subsection.
3. Model initialization requirements.

<u>Submodel Identification</u>

- Team member expertise.
- Team member availability.
- Team member learning requirements.

<u>Submodel Requirements Identification</u>

<u>Model Initialization Requirements</u>

***4) Develop Submodel***

- Name the variables and stocks that will be visible to other submodels
- Use only available software and hardware.
- Rely only on available external submodel outputs.
- Generate all outputs required from the model.
- Use and generate all inputs and outputs with respect to the units agreed upon at the group level.
- Complete Submodel development within the negotiated time frames.
- Communicate all required changes quickly and with sensitivity to other submodel teams.
- Continually monitor the submodel's internal state and external input variables to determine whether the submodel is operating within reasonable or experimental parameters.

***5) Develop Full Model***

1. Plug two submodels together, test
1. Add another, test
2. Repeat

***6) Iteratively Test and Debug***

# A NEPA WORKBENCH

## *DREAM*

I want a system that allows me, in a standard accepted manner, to

- Rapidly assess the potential impact of my proposed project on the local
  - economics
  - hydrology
  - habitat
  - social systems
  - air and water quality
- Identify applicable local, state, and federal regulations
- Rapidly acquire maps of the area
  - Orthophotos
  - Land use, land cover
  - DEM
  - Soils
  - Habitats
  - Threatened and endangered species
  - Roads
  - Population
- Sd
- Sources of funding and assistance

Typical mismatch –

Information is assembled by a providers expertise – not by a user's need.

> *Imagine a system that allowed you to identify your geographic area and, behind the scenes, a comprehensive report on your area is automatically generated through automated access of many Internet sources.*

## *EXAMPLES OF PIECES*

### Economic Impact Forecast System (EIFS)

Purpose: Identify the regional economic impact of a change in job patterns.
Inputs: A set of counties and a change in jobs
Output: Local economic multiplier, total change in jobs (total and by sector)

### Computerized Environmental Legislative Data System (CELDS)

Purpose: Discover state and federal laws associated with a project
Inputs: Keywords
Outputs: Law citations and summaries

### Environmental Impact Computer System (EICS)

Purpose: Narrow the scope of an EIA or EIS
Inputs: Answers to a series of questions about your project
Output: Identification of areas of most and least concern for in-depth analysis

### Know Your Watershed

Existing EPA site that allows you to access lots of information about any US watershed including maps, point pollution sources, historic information, pollution records, etc.

## SUMMARY

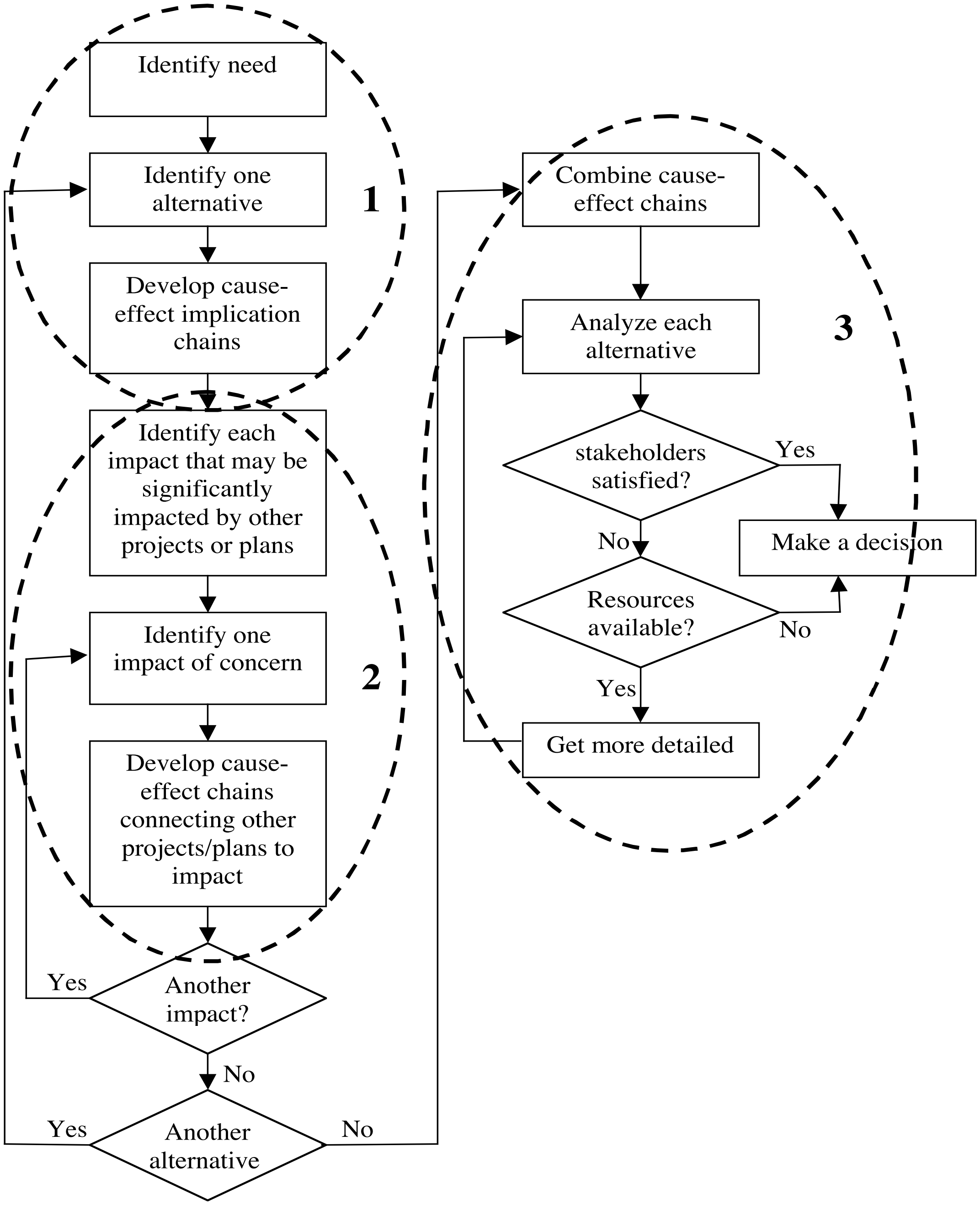


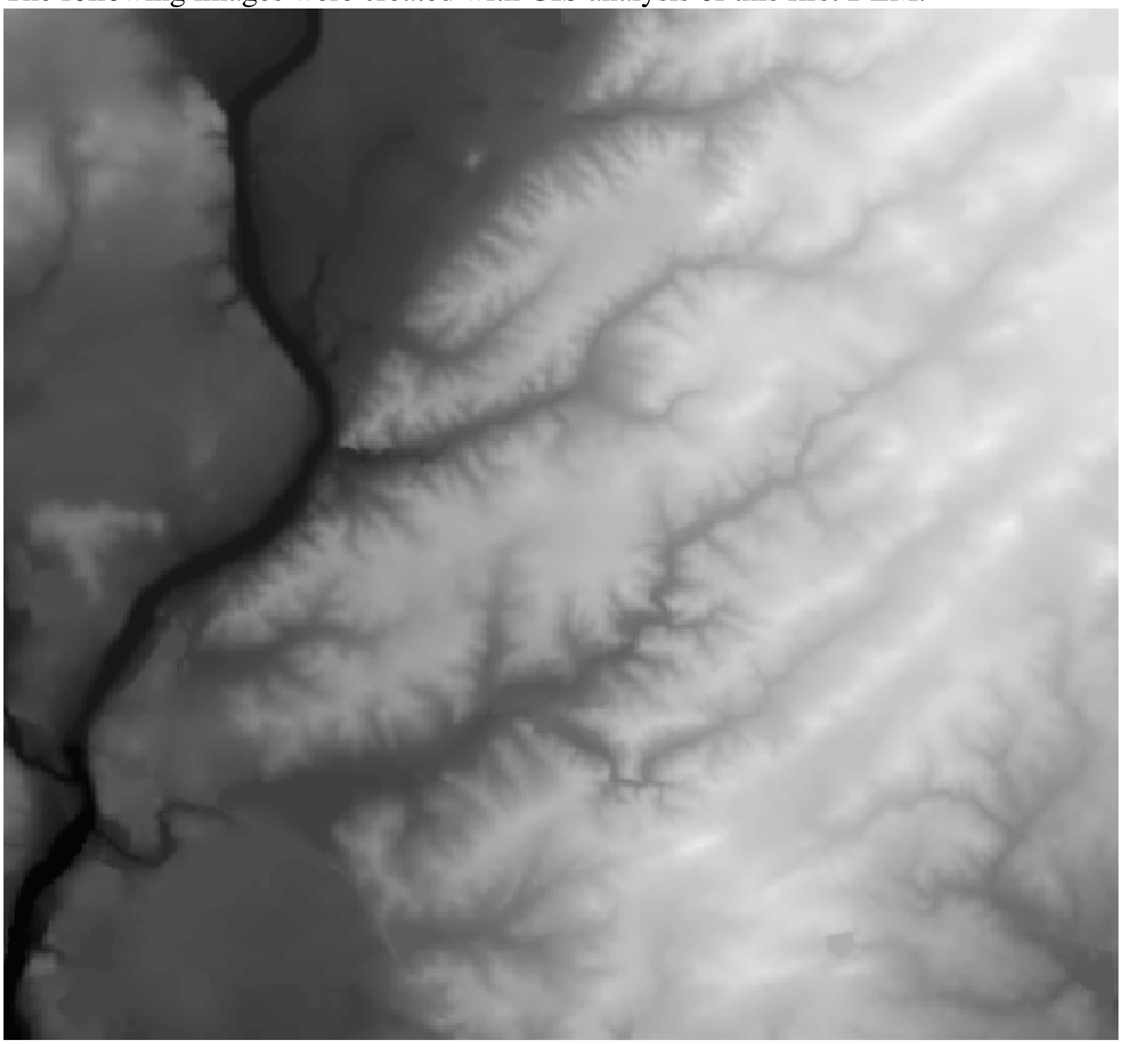

**Figure 21: Summary Flow Chart**

1. Cumulative impact analysis can significantly improve the legally required analyses of proposed federal projects. Area number 1 in Figure 21 is already accomplished in standard analyses. Full consideration of cumulative impacts requires the scoping steps in area 2 and analysis steps in area 3.
2. Cumulative impact analyses must proceed as part of the study process rather than as a final thought.
3. The quickest and least expensive analysis that will satisfy regulations and stakeholders is all that is necessary.
4. Start cheap and get more expensive only when apparently needed.
5. Cumulative impact analysis is a community process – supported by specialists, scientists, and legal consultants.

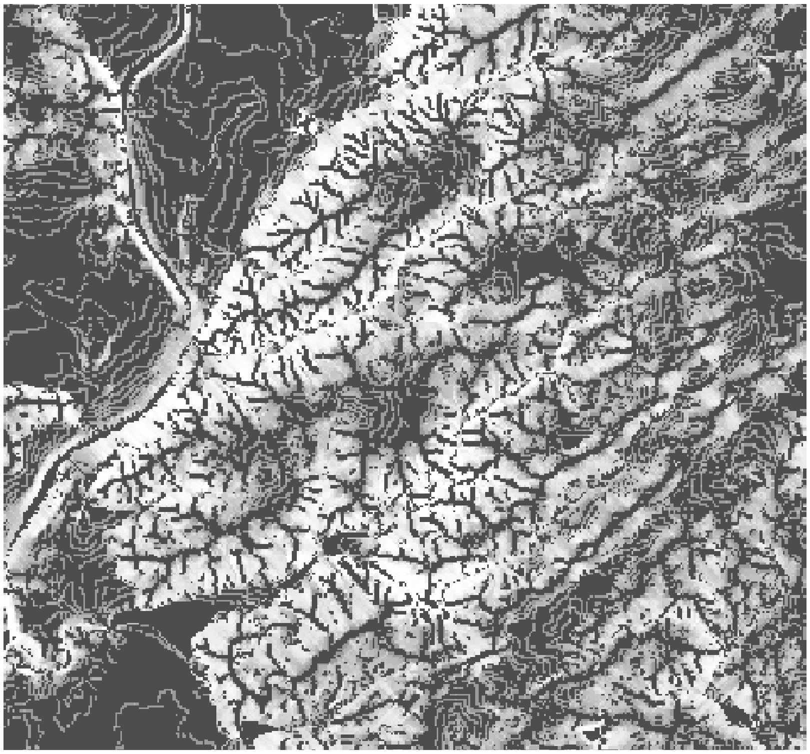
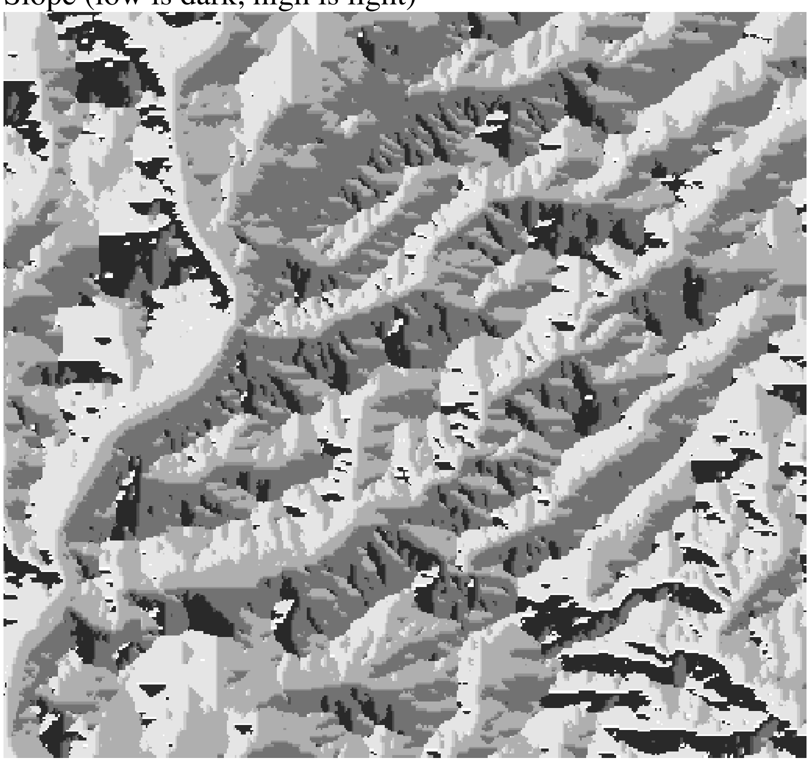
6. Analyses start with stakeholder development of cause-effect chains that capture the way the project touches important aspects of the system.
7. Stakeholder (including laws, lawmakers, and regulatory agencies) interests and tradeoffs among competing goals must be considered. If quantified they can help find acceptable balances.
8. GIS is vital. Can be educational. Can help break apparent cause-effect chains by showing discontinuities in time and or space.

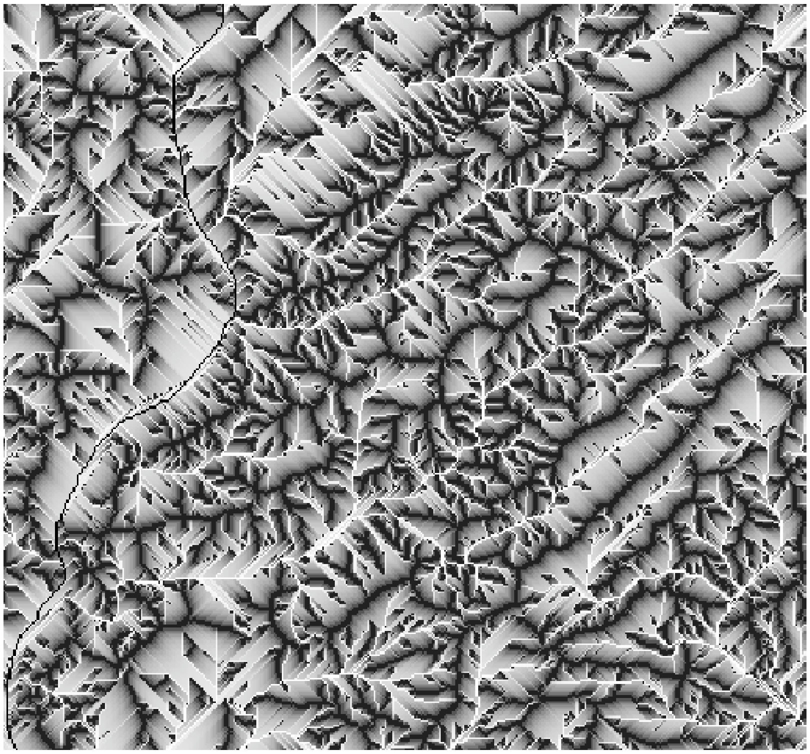
## Appendix A: DEM Fun

Digital elevation models (DEM) provide a cornerstone for doing any serious analysis of a local system. They are generated variously from manual or automated digitization of historic quad sheets, automated processing of pairs of digital images taken at altitude or from satellite, or from direct automated measurement of distance from an aircraft or satellite using various wavelengths (e.g. radar, radio, or laser). Once a DEM is acquired, many secondary maps/images can be generated or constructed. The first image below associates a grey-scale color table to elevations from an area in northern Illinois. Elevations range from low (dark) to high (white). The following images were created with GIS analysis of this first DEM.

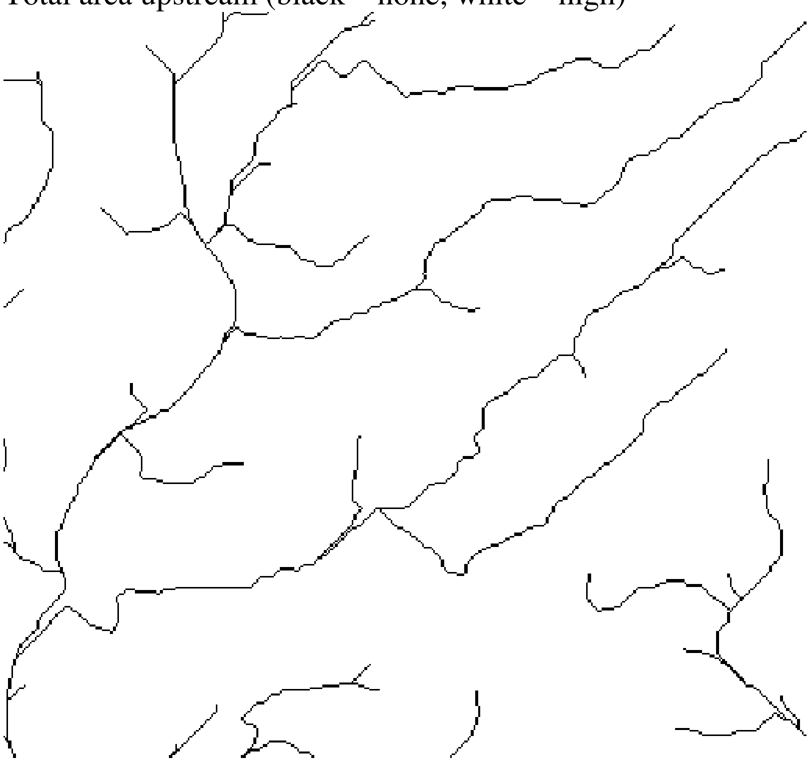


Sample Digital Elevation Model (DEM)

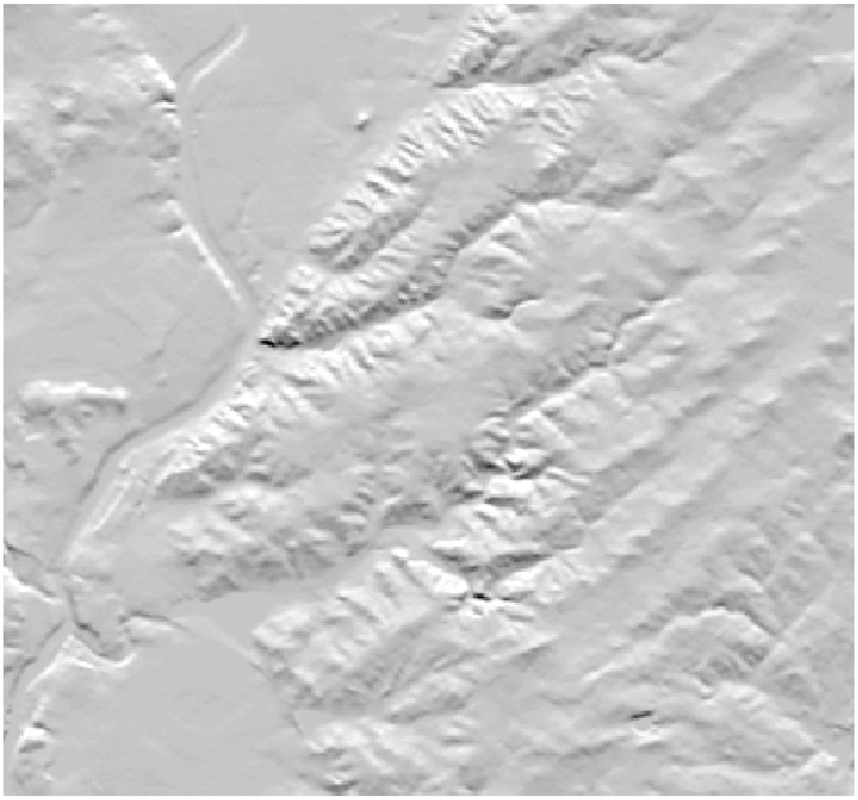
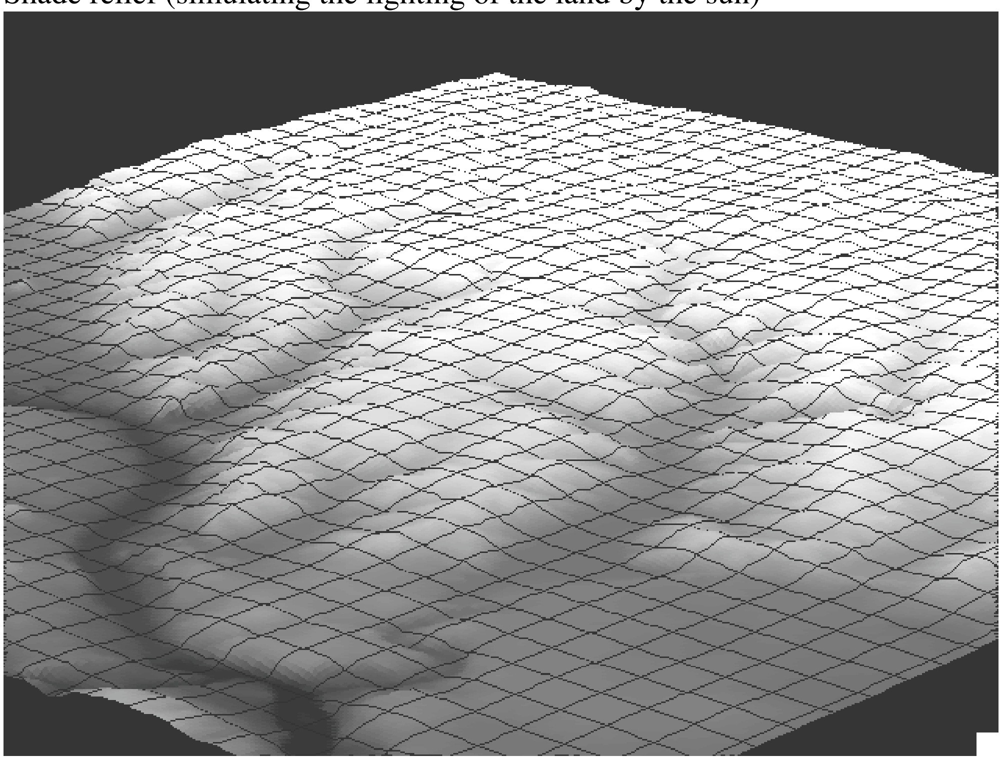

Slope (low is dark, high is light)

Aspect (direction of slope)



Total area upstream (black – none, white – high)



Location of streams


Shade relief (simulating the lighting of the land by the sun)

3-D display (here elevation color is overlaid on elevation height)

# Appendix B: Five Approaches to Modeling

### *Common Sense Models*

For this discussion, common sense models are the conceptual models that we all carry with us. They are our informal understanding of how the world works and they allow us to choose courses of action. As we get older, our models become more finely tuned through the trial and error of experience. We do not automatically develop identical common sense models and we all find ourselves musing how certain others have managed to survive so long with their “crazy” ideas. Language allows us to communicate, with difficulty, our different models to one another – sometimes resulting in surprise and shock. Common sense, we often find, is not commonly shared. Each of us develops a slightly different model of our shared space. If these models get us across the street, allow us to build careers, help us to communicate with others, and are sufficiently accurate predictors of future consequences of our actions, then we get along quite well with the world.

Our “common sense” models of the world are extremely multi disciplinary. Crossing the street involves complex considerations about the physics of moving vehicles, psychology of the local drivers, and our own physical capabilities. Beneath this level is the complex coordination of our muscles and the associated neural processes. Imagine programming a computer to cross roads and it is easy to appreciate the power and complexity of our standard get-through-life models. In a watershed setting, our models associate rain with river levels, seasons with vegetation, clouds with expected weather, bare ground with silt loads, and location of construction with flooding risk. Our models are very inexpensive from the standpoint of marginal cost — because they are ready to use at any time. Education (formal and informal) is the process that develops, tests, and improves models, and provides our common sense models with data. Although extremely useful and immeasurably valuable, common sense models lack a certain formality required for unambiguous communication between individuals. Sometimes our personal common sense models can be reduced to a “rule of thumb”.

### *“Rule of Thumb” Models*

Common sense models, that are easy to state and easy to accept, can become part of our common culture. We pass these between ourselves as a “rule of thumb” model. An engineer might design a bridge to accept anticipated loads and then triple the strength of the beams. A gardener might plant bulbs at a depth three times the bulb diameter in the south — four times in the north. A project bidder might estimate the expected time the project should take and then bid double that estimate. Consider crossing the street: f the light is red, don’t walk. Often, complex scientific research and related models will yield a new rule. Many scientific studies and complex chemical pathway models back up the rule that moderate exercise decreases many health risks. “Rules of thumb” are very simple statements that make decision-making easy. They do not provide reasons for the decisions, but they can be accurate and useful.

### *Expert Models*

Expert models are similar to common sense models in that they are the conceptual models that have developed through years of training, study, and practice in a particular discipline. A visit to the doctor, lawyer, teacher, or scientist puts us in touch with much more sophisticated and elaborate models of the world with respect to the discipline that individual represents. A degree or certification on the wall of the professional is recognition that the individual shares at least part of their model or view of the world with a governing board in that profession. A visit by a plumber, electrician, health care worker, or builder similarly puts us in touch with worldviews accepted and shared by their respective disciplines. These professionals all have highly developed expertise-based conceptual models of certain aspects of the world. We can tap into that expertise, for a price, at any time. Scientists, engineers, and their expertise traditionally have been powerful forces in the management of watersheds, lakes, rivers, and streams. Governing bodies controlling vast stretches of land could tap scientists and engineers for the development of a management plan. Dams could be constructed, lakes created, swamps drained, and rivers rerouted — all based on the expertise embodied in formal professions. Professional expertise is always in flux because of new knowledge emerging from basic and applied research efforts. And it is possible to have competing and disagreeing expert models within any given profession.

### *Scientific Models*

A scientific model is a formalization of an expert's conceptual model into a form that can be communicated directly to other experts. Such models can be expressed in text through refereed journal articles. They may also be expressed as formalized algorithms captured in computer instructions. In journal articles, other scientists can study, replicate, and thoroughly analyze the accuracy of the described understanding or model. In computer software, a computer can reflect back to the scientist the implications and consequences of the model under different constraints. Models that hold up to the scrutiny of other scientists become valuable currency from which new technical innovations are developed and change our world.

Formalized scientific models are less common than expert opinion because few opinions can hold up to scrutiny from a body of individuals. A formal model that has held up well to scrutiny can be useful in building consensus and informing the judgment of expert opinion.

Scientific models can be very useful to watershed management. **Error! Reference source not found.** reviews a good number of single-discipline science-based models that have been developed to support watershed management. One serious challenge to such models is that each typically models some aspect of the watershed processes in some significant detail, but models other aspects in a very simple manner, and sometimes not at all. A hydrologic simulation model might hold the landscape characteristics, like vegetation cover, constant while modeling the flow of water in great detail. A vegetation succession model, on the other hand, may change plant species densities over time based on detailed plant interactions with other plants, soil characteristics, and nutrients. But, it uses annual average soil-moisture indices and completely neglects storm water runoff. Consequently, the hydrologic and vegetation succession models might lead to very different management approaches.

### *Multi disciplinary Management Models*

In response to the shortcomings of single-discipline scientific models, many scientists are collaborating to build integrated multi disciplinary models in support of watershed management. Serious challenges to these efforts include the development of difficult standards for software interaction, the cost of integration, and the acceptance by watershed management groups of the veracity of the integrated models.

### *Which Modeling Approach is Best*

On a day-to-day basis, managers rely on the informal common sense models, rule of thumb models, and expert models. The formal scientific and multi disciplinary models are used by scientists and can affect management decisions through refinement of a manager's informal modeling approaches. Determination of the appropriate modeling approach is based on a number of complex and interrelated issues. Funding, time, accuracy requirements, legal precedents, local expertise, stakeholder interest, scientific knowledge, and success of others all contribute to the decision. Funtowicz and Ravetz (1991) argue that two of these factors can be used to identify the appropriate decision-making level: stakeholder interest and scientific knowledge. If the stakes are low and the scientific uncertainty is low (that is, the science is well understood), applied science is sufficient. If the stakes and/or the uncertainty are higher, then professional consultancy must replace the applied science. If either is higher still, the decision must be established through "post-normal science". "Post-normal" marks the passing of the time when focused science was believed philosophically, if not always practically, sufficient to address societal challenges. Funtowicz and Ravetz (1991) reflect on a new age in which science provides partial insights that must be enriched with local experience, extended peer group insights, and appreciation for the beliefs and feelings of stakeholders. They define the following three continuous approaches to decision-making: applied science, professional consultancy, and post-normal science. Decisions made at the wrong level may not be implemented, may be overly costly, and may need to be rethought. Parallels can be drawn between these approaches and associated modeling techniques. Scientific models are adequate for the application of applied science in the face of low stakeholder interest and low uncertainty. Expert models support professional consultancy, and “post-normal science” is supported by idea models.

Each of these modeling paradigms or approaches can be valuable in land management. Scientific models can be sufficient if scientific certainty is high and if stakeholder interests are low. Stakeholders are not going to take the time to involve themselves due to lack of interest. If the uncertainty and/or the stakeholder interests are higher, science-based models are inadequate, though potentially still valuable, and expert opinions can be sufficient. Higher interest and/or higher uncertainty requires that the final decisions rest with the political processes. Here, science-based models can be used to support expert opinions that in turn are entered as testimony to the political process.

## Appendix C: Modeling Wisdom

*A model is not done when nothing else can be added, but when nothing else can be removed.    - A. Einstein*

*All models are wrong – but some are useful.    – George Box*

*Models are to be used, but not be believed.    – Henry Thiel*

*Model at the scale one step below the scale of the question.*

*Model development must follow questions - the reverse doesn't work.*

*Calibrate a model for the specific question asked.*

*Model answers are only complete if model certainty is given.*

*A model is a very incomplete abstraction of the reality.*

*A modeling team is more valuable than a model.*

*Models enlighten discussion, they do not provide answers.*

# Appendix D: Internet Web Sites To Support Source Water

(modified from: http://nwqmc.site.net/98proceedings/Papers/60-roy.htm)

| | |
|---|---|
| **Assessments and Protection** | |
| Better Assessment Science Integrating Point and Non-Point Sources (BASINS) | http://www.epa.gov/OST/BASINS |
| Clean Water Needs Survey | http://www.epa.gov/OWM/mtb/cwns/index.htm |
| Effluent Guidelines Studies | http://www.epa.gov/records/policy/schedule/sched/414.htm |
| Environmental Monitoring Methods Index | http://www.epa.gov/waterscience/methods/ |
| Index of Watershed Indicators (IWI) | http://www.epa.gov/iwi/ |
| Ocean Data Evaluation System | http://www.epa.gov/records/policy/schedule/sched/368.htm |
| Permit Compliance System | http://www.epa.gov/owmitnet/pcsguide.htm |
| Reach File | http://www.epa.gov/waters/doc/rfindex.html |
| Safe Drinking Water Information System/Federal Version | http://www.epa.gov/safewater/databases.html |
| STORET | http://www.epa.gov/STORET/ |
| Surf Your Watershed (SURF) | http://www.epa.gov/surf |
| The Waterbody System | http://www.epa.gov/records/policy/schedule/sched/446.htm |
| **EPA, Office of Water Information Systems, Models and Tools** | |
| National Listing of Fish and Wildlife Consumption Advisories | http://www.epa.gov/OST/fishadvice/ |
| National Sewage Sludge Survey | http://yosemite.epa.gov/water/owrccatalog.nsf/0/b0f0923099ac13c585256b0600724297?OpenDocument |
| National Volunteer Monitoring Directory | http://www.epa.gov/owow/monitoring/dir.html |
| National Small Flows Clearinghouse List Server | http://www.nwqmc.org/98proceedings/Papers/60-roy.htm |
| Land Cover Digital Data Directory for the United States | http://www.epa.gov/owow/watershed/landcover/index.html |
| Office of Science and Technology (OST) Clearinghouse | http://yosemite.epa.gov/water/owrccatalog.nsf/ |
| Beach Watch | http://www.epa.gov/OST/beaches |
| CORMIX (Cornell Mixing Zone Expert System) | http://www.epa.gov/OWOW/watershed/tools/model.html#3 |
| DYNTOX | http://www.epa.gov/OWOW/watershed/tools/model.html#5 |
| HSPF | http://www.epa.gov/OWOW/watershed/tools/model.html#12 |
| QUAL2E Enhanced Stream Water Quality Model User Interface | http://www.epa.gov/ostwater/QUAL2E_WINDOWS/metadata.txt.html |
| SWMM Storm Water Management Model User Interface | http://www.epa.gov/ednnrmrl/swmm/ |
| PRELIM Version 5 | http://www.epa.gov/owmitnet/pipes/prloclim.htm |
| Other Water Information Systems, Models and Tools | |

| | |
|---|---|
| USGS Water Resources Scientific Information Center (WRSIC) | http://www.uwin.siu.edu/databases/wrsic/index.html |
| National Water-Use Information Program | http://water.usgs.gov/public/watuse/wunwup.html |
| National Oceanic Data Center (NODC) | http://www.nodc.noaa.gov |
| National Ground Water Information Center | http://www.h2o-ngwa.org/about/ |
| Agriculture Research Service (ARS) Water Data Base | http://hydrolab.arsusda.gov/arswater.html |
| AQUatic Toxicity Information REtrieval (AQUIRE) database | http://www.epa.gov/earth100/records/a00120.html |
| Chemical Hazards Response Information System and the Hazard Assessment System (CHRIS/HACS) | http://www.ccohs.ca/products/databases/chris.html |
| EPA Spatial Data Library System (ESDLS) | http://www.epa.gov/nsdi/projects/pgm_hi15.htm |
| Estuarine Living Marine Resources (ELMR) | http://biogeo.nos.noaa.gov/products/data/elmr |
| Integrated Risk Information System (IRIS) | http://www.epa.gov/iris |
| Integrated Taxonomic Information System (ITIS) | http://www.itis.usda.gov/itis/index.html |
| Land Use and Land Cover Digital Data (LULC) | http://edc.usgs.gov/products/landcover/lulc.html |
| National Coastal Pollutant Discharge Inventory Program (NCPDI) | http://www.pubs.asce.org/WWWdisplay.cgi?9302988 |
| National Coastal Wetlands Inventory | http://www.neonet.nl/ceos-idn/datasets/NOS00038.html |
| National Contaminant Biomonitoring Program (NCBP) Data Base | http://www.cerc.cr.usgs.gov/data/ncbp/ncbp.html |
| National Estuarine Inventory (NEI) | http://www.epa.gov/iwi/1999sept/iv15_usmap.html |
| NatureServe | http://www.natureserve.org/ |
| National List of Vascular Plant Species That Occur in Wetlands | http://www.nwi.fws.gov/bha/lists.html |
| National Resources Inventory | http://www.ftw.nrcs.usda.gov/nri_data.html |
| National Shellfish Register | http://www-orca.nos.noaa.gov/projects/95register |
| National Status and Trends Data Base (NSTDB) | http://seaserver.nos.noaa.gov/projects/nsandt/nsandt.html |
| National Water Information System (NWIS) | http://h2o.usgs.gov/public/nawdex/wats/intro.html |
| National Water-Use Data System (WUDS) | http://water.usgs.gov/public/watuse/guidelines/awuds.html |
| Toxic Chemical Release Inventory System (TRIS) | http://www.epa.gov/enviro/html/tris/tris_query.html |
| Ground Water On-Line | http://www.ngwa.org/gwonline/ |
| Master Water Data Index (MWDI) | http://water.usgs.gov/public/nawdex/mwdi.html |
| NOAA Environmental Services Data Directory (NOAADIR) | http://www.esdim.noaa.gov/NOAA-Catalog/ |
| National Environmental Data Referral Service (NEDRES) | http://www.eis.noaa.gov/ |
| National Wetlands Inventory Database | http://wetlands.fws.gov/ |
| National Wetlands Research Center | http://www.nwrc.usgs.gov/ |
| Envirofacts Warehouse | http://www.epa.gov/enviro/index_java.html |
| Maps On Demand (MOD) | http://rockyweb.cr.usgs.gov/mod/ |
| NOAAServer | http://www.esdim.noaa.gov/NOAAServer/ |
| Susceptibility Determination Tools | http://www.epa.gov/safewater/protect/feddata/susceptibility.html |

| Government Agencies | |
|---|---|
| United States Environmental Protection Agency (EPA) | http://www.epa.gov/ |
| EPA Office of Water | http://www.epa.gov/ow/ |
| OW Water Resource Center | http://www.epa.gov/safewater/resource/ |
| American Indian Environmental Office | http://www.epa.gov/indian/ |
| Office of Ground Water and Drinking Water | http://www.epa.gov/OGWDW/ |
| Office of Science and Technology | http://www.epa.gov/OST |
| Office of Wastewater Management | http://www.epa.gov/OW-OWM.html |
| Office of Wetlands, Oceans, & Watersheds | http://www.epa.gov/OWOW/ |
| Region 1—CT, MA, ME, NH, RI, VT | http://www.epa.gov/region1 |
| Region 2—NJ, NY, Puerto Rico and the Virgin Islands | http://www.epa.gov/region2 |
| Region 3—DE, MD, PA, VA, WV, and DC | http://www.epa.gov/region3 |
| Region 4—AL, FL, GA, KY, MS, NC, SC, and TN | http://www.epa.gov/region4 |
| Region 5—IL, IN, MI, MN, OH, and WI | http://www.epa.gov/region5 |
| Region 6—AR, LA, NM, OK, and TX | http://www.epa.gov/region6 |
| Region 7—IA, KS, MO, and NE | http://www.epa.gov/region7 |
| Region 8—CO, MT, ND, SD, UT, and | http://www.epa.gov/region8 |
| Region 9—AZ, CA, HI, NV, Guam & American Samoa | http://www.epa.gov/region9 |
| Region 10—AK, ID, OR, and WA | http://www.epa.gov/region10 |
| Chesapeake Bay Program | http://www.epa.gov/r3chespk/ |
| Coastal America | http://www.epa.gov/owow/oceans/partnerships/coastam.html |
| Great Lakes Program | http://www.epa.gov/glnpo/ |
| Great Lakes Information | http://www.great-lakes.net/ |
| Gulf of Mexico Program | http://www.epa.gov/gmpo/ |
| National Oceanic and Atmospheric Administration (NOAA) | http://www.noaa.gov |
| Climate Diagnostics Center | http://www.cdc.noaa.gov/ |
| Climate Monitoring and Diagnostics Laboratory | http://www.cmdl.noaa.gov/ |
| NOAA Research | http://www.research.noaa.gov/ |
| Hydrologic Information Center NWS, NOAA | http://www.nws.noaa.gov/oh/hic/ |
| National Centers for Environmental Prediction (NCEP) | http://wwwt.ncep.noaa.gov/ |
| National Climatic Data Center | http://www.ncdc.noaa.gov |
| National Oceanographic Data Center | http://www.nodc.noaa.gov/ |
| National Weather Service (NWS) | http://www.nws.noaa.gov |
| NOAA Network Information Center | http://www.cio.noaa.gov/hpcc/projects/200002.html |
| Army Corps of Engineers | http://www.usace.army.mil/ |
| U.S. Army COE—Waterways Exp. Station (WES) | http://www.wes.army.mil/WES/welcome.html |
| United States Fish & Wildlife Service | http://www.fws.gov/ |
| U.S. FWS National Wetlands Inventory | http://www.nwi.fws.gov/ |
| United States Geological Survey (USGS) | http://www.usgs.gov/ |
| Federal Geographic Data Committee | http://fgdc.er.usgs.gov/fgdc.html |
| National Water Conditions | http://water.usgs.gov/nwc/ |
| National Water Data EXchange (NAWDEX) | http://water.usgs.gov/nawdex/nawdex.html |

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| USGS—Water Resources Division | http://water.usgs.gov/ |
| USGS Node National Geospatial Data Clearinghouse | http://nsdi.usgs.gov/ |
| National Center for Atmospheric Research (NCAR) | http://www.ucar.edu/ |
| National Operational Hydrologic Remote Sensing Center | http://www.nohrsc.nws.gov |
| National Rural Water Association (NRWA) | http://www.nrwa.org/ |
| National Science Foundation | http://www.nsf.gov |
| Natural Resources Conservation Service (NRCS) | http://www.nrcs.usda.gov/ |
| Rural Utilities Service, Water And Waste Program (USDA) | http://www.usda.gov/rus/water/ |
| United States Bureau of Reclamation | http://www.usbr.gov |
| **State Environmental Agencies** | |
| Alabama | http://www.alabama.gov |
| Alaska Dept of Env. Conserv. | http://www.state.ak.us/dec/ |
| Arizona Fish and Game | http://www.state.az.us/game |
| Arizona Water Resources Research Center | http://ag.arizona.edu/AZWATER |
| Arkansas | http://www.state.ar.us/ |
| California | http://my.ca.gov/state/portal/myca_homepage.jsp |
| California EPA | http://www.calepa.ca.gov/ |
| California Department of Water Resources | http://wwwdwr.water.ca.gov/ |
| California Watershed Projects Inventory (CWPI) | http://ice.ucdavis.edu/ |
| California Rivers Assessment (CARA) | http://ice.ucdavis.edu/California_Rivers_Assessment/ |
| Colorado Water Resources | http://co.water.usgs.gov/ |
| Colorado State Univ.—Water | http://watercenter.colostate.edu/ |
| Colorado Water Resources Research Institute | http://yuma.acns.colostate.edu/Depts/CWRRI/ |
| Colorado Department of Public Health and Environment | http://www.cdphe.state.co.us/cdphehom.asp |
| Connecticut Department of Environmental Protection | http://dep.state.ct.us/ |
| Delaware | http://delaware.gov/ |
| Delaware Dept. of Nat. Res. And Environmental Control | http://www.dnrec.state.de.us/ |
| Florida Department of Environmental Protection | http://www.dep.state.fl.us/ |
| Georgia DNR | http://www.gadnr.org/ |
| Georgia Home Page | http://www.state.ga.us/ |
| Hawaii Department of Land and Natural Resources | http://www.state.hi.us/dlnr/Welcome.html |
| Idaho Department of Health and Welfare | http://www2.state.id.us/dhw/ |
| Idaho Emergency Response Commission | http://www2.state.id.us/serc/ |
| Illinois EPA | http://www.epa.state.il.us/ |
| Indiana Water Resources Research Center | http://ce.ecn.purdue.edu/wrrc.html |
| Indiana Department of Natural Resources | http://www.in.gov/dnr |
| Iowa Department of Natural Resources | http://www.iowadnr.com/ |
| Kansas Department of Health and Environment | http://www.kdhe.state.ks.us/ |
| Kansas Northwest Goundwater Mgmt. District #4 | http://www.gmd4.org/ |
| Kentucky Environmental Quality Commission | http://www.eqc.ky.gov/ |
| Louisiana Department of Environmental Quality | http://www.deq.state.la.us/ |
| Maine Department of Environmental Protection | http://www.maine.gov/dep/index.shtml |

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| Maine DEP, Bureau of Land & Water Quality | http://www.maine.gov/dep/blwq/ |
| Maryland Department of the Environment | http://www.mde.state.md.us |
| Maryland Department of Natural Resources | http://www.dnr.state.md.us/ |
| Massachusetts Department of Environmental Protection | http://www.magnet.state.ma.us/dep/dephome.htm |
| Michigan Department of Environmental Quality | http://www.michigan.gov/deq |
| Minnesota | http://www.dnr.state.mn.us/ |
| Mississippi | http://www.state.ms.us/ |
| Missouri Department of Conservation Home Page | http://www.conservation.state.mo.us/ |
| Missouri DNR, Division of Environmental Quality | http://www.dnr.state.mo.us/ |
| Montana Dept. of Natural Resources and Conservation | http://www.dnrc.state.mt.us/ |
| Montana Natural Resource Information System | http://nris.state.mt.us/ |
| Montana GIS Data Library | http://nris.state.mt.us/gis |
| Nebraska Natural Resources Commission | http://www.dnr.state.ne.us/databank/meetings/costrec.html |
| Nebraska Water Center /Environmental Programs Unit | http://watercenter.uni.edu |
| Nevada | http://www.state.nv.us/ |
| New Hampshire Department of Environmental Services | http://www.des.state.nh.us |
| New Jersey Department of Environmental Protection | http://www.state.nj.us/dep/ |
| New Mexico Environment Department | http://www.nmenv.state.nm.us/ |
| New Mexico Water Resources Research Institute | http://wrri.nmsu.edu/ |
| New York State Department of Environmental Conservation | http://www.dec.state.ny.us |
| North Carolina Dept. of Env., Health and Nat. Res. | http://www.enr.state.nc.us/ |
| North Carolina GIS Database | http://cgia.cgia.state.nc.us/ |
| North Carolina - Division of Water Resources | http://www/ncwater.org |
| North Carolina Water Resources Research Institute | http://www2.ncsu.edu/ncsu/CIL/WRRI |
| North Dakota State Water Commission | http://www.swc.state.nd.us |
| North Dakota Geological Survey Division | http://www.state.nd.us/ndgs/ |
| Ohio Environmental Protection Agency | http://www.epa.state.oh.us/ |
| Oklahoma Conservation Commission | http://www.okcc.state.ok.us/ |
| Oklahoma Department of Environmental Quality | http://www.deq.state.ok.us |
| Oregon Department of Fish and Wildlife | http://www.dfw.state.or.us/ |
| Oregon Department of Environmental Quality | http://www.deq.state.or.us/ |
| Pennsylvania Department of Environmental Protection | http://www.dep.state.pa.us/ |
| Pennsylvania Dept. of Conservation and Natural Resources | http://www.dcnr.state.pa.us |
| Rhode Island | |
| South Carolina Department of Natural Resources | http://www/dnr.state.sc.us/ |
| South Carolina Dept. of Health and Environmental Control | http://www.scd.hec.net/ |
| South Dakota Dept. of Environment and Natural Resources | http://www.state.sd.us/denr/denr.html |
| Tennessee Department of Environment and Conservation | http://www.state.tn.us/environment/ |

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| Texas Natural Resources Conservation Commission | http://www.tceq.state.tx.us/ |
| Texas State Agencies | http://www.texas.gov/ |
| Texas Environmental Center | http://www.tec.org/ |
| Utah Water Research Laboratory | http://www.engineering.usu.edu/uwrl |
| Utah Department of Environmental Quality | http://www.eq.state.ut.us/ |
| Utah Automated GIS Reference Center | http://agrc.its.state.ut.us/agrc_sgid/sgidintro.html |
| Vermont Agency of Natural Resources | http://www.state.vt.us/anr/ |
| Virginia Department of Environmental Quality | http://www.deq.state.va.us |
| Washington State Department of Ecology | http://www.wa.gov/ecology/ |
| Washington Department of Transp Env. Affairs Office | http://www.wsdot.wa.gov/environmentt |
| West Virginia Division of Env. Protection | http://www.dep.state.wv.us/ |
| Wisconsin State Agencies | http://www.wisconsin.gov/ |
| Wyoming Department of Environmental Quality | http://deq.state.wy.us |
| Wyoming Water Resources Center | http://www.wwrc.uwyo.edu/ |
| Powell Consortium. (AZ, CA, CO, NM, NV, UT & WY) | http://wrri.nmsu.edu/powell |
| **International Environmental Organizations** | |
| Environment Australia | http://www.environment.gov.au/ |
| Division of Water Resources CSIRO | http://www.austehc.unimelb.edu.au/asaw/biogs/A000671b.htm |
| International Groundwater Modeling Center (IGWMC) | http://typhoon.mines.edu/ |
| National Water Research Institute (Canada) | http://www.cciw.ca/nwri/intro.html |
| University of Western Australia—Centre for Water Research | http://www.cwr.uwa.edu.au |
| WQ Branch, BC Ministry of Env., Lands & Parks | http://www.gov.bc.ca/bvprd/bc/channel.do?action=ministry&channelID=-8395&navId=NAV_ID_province |
| Water Resources Systems Research Unit | http://www.ncl.ac.uk/wrgi/wrsrl/ |
| Environment Canada | http://www.ns.ec.gc.ca/index_e.html |
| **Private/Industry/Academic Organizations** | |
| American Water Resources Association (AWRA) | http://www.awra.org/ |
| American Water Works Association (AWWA) | http://www.awwa.org/ |
| Farm*A*Syst/Home*A*Syst | http://www.wisc.edu/farmasyst |
| National Drought Mitigation Center | http://www.drought.unl.edu/dm/index.html |
| National Institutes for Water Resources | http://wrri.nmsu.edu/niwr/ |
| Wasser & Boden (Water & Soil) (German) | http://www.blackwis.de/wabo.htm |
| Water Environment Federation | http://www.wef.org/ |
| **Collections of Water Information and Data Sources** | |
| Air and Water Quality (Environment) Directories | http://www.galaxy.com/galaxy/Community/Environment/Air-and-Water-Quality.html |
| Bottled Water Web | http://www.bottledwaterweb.com/ |
| Browse EPA Topics | http://www.epa.gov/epahome/browse.htm |
| Encyclopedia of Water Terms | http://www.tec.org/tec/terms2.html |
| Engineers Online | http://www.engineersonline.com |
| Environment Online | http://www.environmentonline.com/ |

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| Environmental Law | http://www.eli.org/ |
| Environmental Professional's Homepage | http://www.clay.net/ep.html |
| EPA Watershed Tools Directory | http://www.epa.gov/OWOW/watershed/tools/ |
| Global Change Master Directory | http://gcmd.gsfc.nasa.gov/index.html |
| Hydrogen Peroxide Online | http://www.h2o2.com |
| Inter-American Water Resources Network (IWRN) | http://www.iwrn.net/ |
| Lifewater International | http://www.lifewater.org/ |
| National Extension Water Quality Database | http://hermes.ecn.purdue.edu:8001/server/water/water.html |
| Pollution Online | http://www.pollutiononline.com |
| Public Works Online | http://www.publicworks.com |
| Selected Info. Res. for NPS Poll. Reduction for MN River Basin | http://www.soils.agri.umn.edu/research/mn-river/doc/edinfowb.html |
| Sewage Net | http://www.sewage.net |
| Software for Ground Water Scientists | http://www.groundwatermodels.com/software/Software.asp |
| Solid Waste Online | http://www.solidwaste.com |
| The EnviroWeb | http://envirolink.org/ |
| Universities Water Information Network (UWIN) | http://www.ucowr.siu.edu/ |
| US National Biological Survey | http://biology.usgs.gov/ |
| Universities Council on Water Resources | http://ucowr.siu.edu |
| Water Resources Databases | http://www.nal.usda.gov/wqic/dbases.html |
| Water Quality Information Center | http://www.nal.usda.gov/wqic/ |
| Water Online | http://www.wateronline.com |
| Water Resources Discussion List | http://www.nal.usda.gov/wqic/lists.html |
| Water Publications Digest | http://www.groundwatersystems.com/wpd.html |
| Waterloo's Environmental Information Systems Project | http://bordeaux.uwaterloo.ca/ |
| WaterWiser: The Water Efficiency Clearinghouse | http://www.waterwiser.org/ |
| WWF Global Network | http://www.panda.org/ |